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PROCEEDINGS
of
The Institute of Radio Engineers

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Institute of Radio Engineers Forthcoming Meetings

PACIFIC COAST MEETING
Spokane, Washington
September 1 and 2, 1937

BUFFALO-NIAGARA SECTION
June 11, 1937

CLEVELAND SECTION
June 24, 1937

DETROIT SECTION
June 18, 1937

LOS ANGELES SECTION
June 15, 1937

WASHINGTON SECTION
June 14, 1937

MELVILLE EASTHAM
Recipient, Institute Medal of Honor, 1937.

Melville Eastham was born on June 26, 1885, at Oregon City, Oregon. In 1905 he became chief engineer of Willyoung & Gibson, instrument manufacturers in New York City. A year later with J. E. Clapp he founded the Clapp-Eastham Company for the manufacture of radio equipment. In 1915 he became President of the newly formed General Radio Company and has been active in that organization since. He has been responsible for the design and development of numerous measuring instruments in the radio field.

In 1913 he entered the Institute as an Associate member and was transferred to the Member grade later in the same year. He became a Fellow in 1925. In 1927 he was elected Treasurer and has continued in that capacity since. He has served on numerous Institute committees and has been a member of the Board of Directors continuously since 1922.

The Institute Medal of Honor for 1937 was presented to Mr. Eastham during the Silver Anniversary banquet of the Institute on May 12, 1937, for his pioneer work in the field of radio measurements, his constructive influence on laboratory practice in communication engineering, and his unfailing support of the aims and ideals of the Institute.

INSTITUTE NEWS AND RADIO NOTES

April Meeting of the Board of Directors

The April meeting of the Board of Directors was held on the 7th in the Institute office and attended by H. H. Beverage, president; Melville Eastham, treasurer; Ralph Bown, Alfred N. Goldsmith, Virgil M. Graham, Alan Hazeltine, L. C. F. Horle, C. M. Jansky, Jr., Haraden Pratt, B. J. Thompson, H. M. Turner, L. E. Whittemore, and H. P. Westman, secretary.

Forty-two applications for Associate membership, two for Junior, and eighteen for Student grade were approved. H. M. Turner was transferred to Fellow grade.

A report was submitted on the progress being made in the preparations for a joint meeting of the Institute and the American Institute of Electrical Engineers in Spokane, Washington, early in September. Arrangements are being made under the supervision of our three Pacific Coast Sections.

The Nominations Committee submitted its report and a detailed account of the names of candidates to be submitted to the membership follows this report.

The Awards Committee submitted its report and the Institute Medal of Honor for 1937 was voted to Melville Eastham for his pioneer work in the field of radio measurements, his constructive influence on laboratory practice in communication engineering, and his unfailing support of the aims and ideals of the Institute.

The Morris Liebmann Memorial Prize, by decision of the Awards Committee, was given to W. H. Doherty for his improvement in the efficiency of radio-frequency power amplifiers.

It was agreed that an invitation be extended to the Radio Club of America to participate in our Silver Anniversary Convention by the presentation, under their sponsorship, of a paper during one of the technical sessions.

The appointment of A. F. Van Dyck, to serve as the representative of the Institute on a conference considering amendments to the model registration law for professional engineers was approved. This conference considered only the model law proposed by the founder societies and took no consideration of any other existing laws.

Nomination of Officers

ARTICLE VII

NOMINATION AND ELECTION OF PRESIDENT, VICE PRESIDENT, AND THREE DIRECTORS AND APPOINTMENT OF SECRETARY, TREASURER, AND FIVE DIRECTORS

SEC. 1—On or before July 1st of each year the Board of Directors shall call for nominations by petition and shall at the same time submit to qualified voters a list of the Board's nominations containing at least two names for each elective office, together with a copy of this article.

Nomination by petition shall be made by letter to the Board of Directors setting forth the name of the proposed candidate and the office for which it is desired he be nominated. For acceptance a letter of petition must reach the executive office before August 15th of any year, and shall be signed by at least thirty-five Fellows, Members, or Associates.

Each proposed nominee shall be consulted and if he so requests his name shall be withdrawn. The names of proposed nominees who are not eligible under the Constitution, as to grade of membership or otherwise, shall be withdrawn by the Board.

On or before September 15th, the Board of Directors shall submit to the Fellows, Members, and Associates in good standing as of September 1st, a list, of nominees for the offices of President, Vice President, and three Directors. This list shall comprise at least two names for each office, the names being arranged in alphabetical order and shall be without indication as to whether the nominees were proposed by the Board or by petition. The ballot, shall carry a statement to the effect that the order of the names is alphabetical for convenience only and indicates no preference.

Fellows, Members, and Associates shall vote for the officers whose names appear on the list of nominees, by written ballots in plain sealed envelopes, enclosed within mailing envelopes marked "Ballot" and bearing the member's written signature. No ballots within unsigned outer envelopes shall be counted. No votes by proxy shall be counted. Only ballots arriving at the executive office prior to October 25th shall be counted. Ballots shall be checked, opened, and counted under the supervision of a Committee of Tellers, between October 25th and the first Wednesday of November. The result of the count shall be reported to the Board of Directors at its first meeting in November and the nominees for President and Vice President and the three nominees for Directors receiving the greatest number of votes shall be declared elected. In the event of a tie vote the Board shall choose by lot between the nominees involved.

SEC. 2—The Treasurer, Secretary, and five appointive Directors shall be appointed by the Board of Directors at its annual meeting for a term of one year or until their successors be appointed.

In accordance with the above constitutional requirements, there is given below a list of the Board's nominations for President, Vice President, and Directors.

For President, 1938

H. M. Turner   Haraden Pratt

For Vice President, 1938

Raymond Braillard	E. T. Fisk

For Directors, 1938–1940

A. B. Chamberlain	L. C. F. Horle
F. W. Cunningham	C. M. Jansky, Jr.
O. B. Hanson	A. F. Murray

Silver Anniversary Convention

Our Silver Anniversary Convention which was held in the Hotel Pennsylvania, New York City, on May 10, 11, and 12 was attended by 1189 members and guests of whom 76 were ladies.

The program as given in the May issue of the PROCEEDINGS was followed closely and a total of thirty technical papers was presented.

Just prior to the opening of the convention and after all advance publicity had been released, arrangements were made for a demonstration of the high definition television system developed by the Radio Corporation of America. Approximately 750 Institute members attended the three demonstrations which were given on the evening of May 11 in the RCA Building. The demonstration included both direct pickup and film-scanned transmissions. Reception was by means of a number of household type television receivers. As the facilities for this demonstration were limited, it was not possible to accommodate nonmembers.

At our Silver Anniversary Banquet, which was held on the evening of the 12th, copies of the first issue of the PROCEEDINGS published were distributed as souvenirs. The issue was reprinted for this purpose by a photographic process giving accurate reproduction of the original material.

The Institute Medal of Honor was presented by President Beverage to Melville Eastham for his pioneer work in the field of radio measurements, his constructive influence on laboratory practice in communication engineering, and his unfailing support of the aims and ideals of the Institute.

The Morris Liebmann Memorial Prize was handed by President Beverage to W. H. Doherty in recognition of his improvement in the efficiency of radio-frequency power amplifiers. Short responses were made by each of the recipients.

R. H. Marriott, the first president of the Institute, spoke on some early radio experiences. Dr. Goldsmith spoke on the early formation of

the Institute, the radio conditions of that time, and the services the Institute might render the profession in the future.

P. P. Eckersley, our vice president, who journeyed from England especially to attend the convention, spoke on radio conditions in Europe and in England. He contrasted broadcasting in that part of the world with the system operative in the United States pointing out various desirable and undesirable characteristics of each.

Thirty-seven exhibitors occupied the forty-one booth spaces available and displayed their latest developments in measuring equipment, vacuum tubes, receiving set and special purpose components, and manufacturing aids.

Committee Work

Awards

A meeting of the Awards Committee attended by Alan Hazeltine, chairman; R. R. Beal, L. M. Hull, Haraden Pratt, L. E. Whittemore and H. P. Westman, secretary, was held on April 7. The recommendations of this committee were submitted to the Board and are given in detail in the report of its April meeting.

Constitution and Laws

The Constitution and Laws Committee met in the Institute office on March 23 and those present were H. M. Turner, chairman; Austin Bailey, Ralph Bown, B. J. Thompson, H. P. Westman, secretary, and J. D. Crawford, assistant secretary. The committee continued its revision of the Institute constitution.

Convention

A meeting of the Silver Anniversary Convention Committee was held in the Institute office on March 31, and attended by H. P. Westman, Chairman; Austin Bailey, J. D. Crawford, Alfred N. Goldsmith, J. D. Parker (representing E. K. Cohan), Haraden Pratt, Mrs. H. S. Rhodes, B. J. Thompson, and A. F. Van Dyck.

Another meeting of this committee was held on April 28 and H. P. Westman, chairman; Austin Bailey, E. K. Cohan, J. D. Crawford, Alfred N. Goldsmith, L. C. F. Horle, J. D. Parker (representing E. K. Cohan), Haraden Pratt, Mrs. H. S. Rhodes, B. J. Thompson, and A. F. Van Dyck were present.

The Subcommittee on Technical Papers of the Convention Committee met on March 30 and those present were William Wilson, Haraden Pratt, and H. P. Westman.

These meetings of the Convention Committee were held to prepare the program for the convention on which a report appears elsewhere in this issue.

Membership

The Membership Committee met in the Institute office on May 3 and those present were H. P. Westman, secretary and acting chairman; Nathaniel Bishop, J. T. Brothers (representing Leslie Woods), H. A. Chinn, I. S. Coggeshall, Coke Flannagan, H. C. Gawler, L. G. Pacent, J. C. Randall, and C. R. Rowe. The meeting was devoted to an examination of the 1937 membership list to prepare recommendations to the Admissions Committee for transfers of existing members to higher grades than those they now hold.

Nominations

The Nominations Committee met on April 6 and those in attendance were C. M. Jansky, Jr., chairman; C. B. Jolliffe, and H. P. Westman, secretary. The committee prepared a slate of nominations and after discussing it by telephone with the remaining members of the committee presented it to the Board of Directors. The details of these proposals are given elsewhere in this issue.

Sections

The annual meeting of the Sections Committee was held in the Hotel Pennsylvania on May 10. The following were present: H. P. Westman, secretary and acting chairman; H. H. Beverage, president; E. L. Bowles, J. E. Brown, H. L. Byerlay, E. D. Cook, L. F. Curtis, F. W. Cunningham, C. L. Davis, R. A. Fox, R. A. Hackbusch, J. K. Johnson, M. I. Kahl, R. H. Klingelhoeffer, B. Lazich, G. F. Platts, G. T. Royden, R. Schaefer, A. F. Shreve, I. M. Slater, and Irving Wolff.

The following sections were represented: Boston, Chicago, Cincinnati, Cleveland, Connecticut Valley, Detroit, Emporium, Indianapolis, Philadelphia, Pittsburgh, San Francisco, Toronto, and Washington.

An analysis of section membership, meetings, and finances was examined and discussed in detail. In regard to penalties for holding fewer than the prescribed five meetings a year, a subcommittee was appointed with power to draft a proposed constitutional amendment covering this subject.

The Secretary was requested to prepare a short instruction manual for the use of newly elected officers of sections.

In order to encourage the publication in the PROCEEDINGS of papers

presented before sections, it was recommended to the Board of Directors that a citation be issued each year to that member of the Institute who, in the opinion of the Awards Committee, has published in the PROCEEDINGS the best paper which has previously been presented before a section meeting.

The meeting was closed with a discussion of the desirability of stimulating members qualified for higher grades in membership to submit applications for transfer to those grades.

STANDARDS

TECHNICAL COMMITTEE ON ELECTROACOUSTICS

The Technical Committee on Electroacoustics met in the Institute office on April 23. Those present were H. F. Olson, chairman; Sidney Bloomenthal, J. T. L. Brown, Knox McIlwain, Hans Roder, Julius Weinberger (guest), and H. P. Westman, secretary.

Answers were prepared to the criticisms of the Standards Committee on the report on loud-speaker testing and on definitions. This completes the report for final submission to the Standards Committee.

TECHNICAL COMMITTEE ON ELECTRONICS

On April 9 the Technical Committee on Electronics met in the Institute office and those present were B. J. Thompson, chairman; J. W. Arnold (representing J. W. Milnor), R. S. Burnap, E. L. Chaffee, F. R. Lack, George Lewis, Ben Kievit, Jr., Knox McIlwain, G. D. O'Neill, Dayton Ulrey, H. P. Westman, secretary, and J. D. Crawford, assistant secretary.

In preparing its report on definitions, this committee adopted a number of items which had been approved by a committee of the American Standards Association. In a few cases, minor changes were suggested to the A. S. A. Committee. A recent meeting of that committee approved these changes, thus changing the A. S. A. form of the definition. The improved form was adopted by the I. R. E. committee at this meeting.

The Standards Committee will be asked to co-ordinate the preparation of letter symbols and to assist in this work a subcommittee was established to prepare the views of the Technical Committee on Electronics for submission to the Standards Committee.

The annual review of developments in radio will be continued as in the last two years and it is the duty of each Technical Committee to prepare a report on activities in its field. To assist in the preparation of this material it was agreed that reference to published material

should be submitted in the form of footnotes and not as a bibliography. Copyrighted names should not be used unless no other simple method of conveying the information is available.

A number of future committee activities were discussed.

Subcommittee on Small High Vacuum Tubes

The Institute Committee on Small High Vacuum Tubes of the Technical Committee on Electronics met in the Institute office on March 16 and those present were P. T. Weeks, chairman; L. E. Barton, R. S. Burnap, G. D. O'Neill, C. B. Upp, and H. P. Westman, secretary.

The committee devoted its time to a discussion of material on which it will attempt to prepare a report for submission to the Technical Committee on Electronics.

Institute Meetings

Atlanta Section

N. B. Fowler, chairman, presided at the March 18 meeting of the Atlanta Section which was held at Broadcast Station WGST. There were thirty-five present.

A paper on "A Modern Broadcast Transmitter" was presented by Ben Ackerman, chief engineer of WGST. The station is housed in a modern fireproof structure and employs an RCA 5C transmitter which energizes a 289-foot vertical radiator. Two sources of primary power are available and in addition an emergency unit is installed in the basement of the building. The performance characteristics of the equipment were described.

A report was presented by H. L. Reid, chairman of the local committee on the status of pending legislation on the registration of engineers.

The April 15 meeting of the section was attended by twenty-nine and held at the Atlanta Athletic Club. Chairman Fowler presided.

G. C. Hawkins, assistant radio engineer of the Department of Commerce, presented a paper on "Progress in the Development of Radio Aids to Air Navigation." He described briefly the problems faced by the Department of Commerce in the pioneer days of aviation and the manner in which they were met. Modern aircraft radio equipment was then described and the use of the Adcock antenna for beam transmitters covered. The paper was terminated with a discussion of developments of the use of ultra-high frequencies as an aid to air navigation.

Motion pictures were then shown to illustrate the type of flying done by commercial air lines in the United States and the equipment employed for this purpose.

Buffalo-Niagara Section

A joint meeting with the Engineering Society of Buffalo was held by the Buffalo-Nigara Section on March 16 at the Hotel Statler in Buffalo. There were 600 present. E. T. Larkin, chairman of the Engineering Society of Buffalo, presided.

"Adventures in Electricity" was the subject of a paper by Phillips Thomas, research engineer of the Westinghouse Electric and Manufacturing Company.

Dr. Thomas first discussed air-conditioning filters. Mechanical devices remove about ninety per cent of the dust leaving extremely fine particles and relatively enormous numbers of bacteria. By charging all solid particles in the air electrically and precipitating them by means of oppositely charged plates, nearly all of the particles and germs may be removed.

The breaking of outdoor conductors during a sleet storm was then discussed. Breakage may be due to a vertical vibration accelerated by the aerodynamic effect of cross wind and may not be primarily caused by the sleet load.

The grid-glow tube was then described. Its high sensitivity was demonstrated by using it in a demonstration whereby the moisture from a person's breath deposited on a piece of glass in the control circuit of the tube sufficiently reduced its impedance to actuate a relay. Another demonstration showed the operation of a phototube actuated by the light from a match as a method of controlling a grid-glow tube which in turn operated a relay.

Dr. Thomas then discussed recent developments in metallurgy applied to permanent magnets having a high degree of retention of magnetic strength.

A demonstration of a stroboscope and its ability apparently to stop periodic motion was then given.

Providing automatic advance to remote control circuits used in large power stations was then described. A one-second lag between the closing of a control circuit and the closing of its large main circuit breaker is sometimes necessary. The demonstration of a relay for this purpose showed the automatic connection of a small synchronous generator to the supply circuit on the lecture platform. The amount of advance was made visible by the use of the stroboscope.

An ignitron tube by means of which the closing and interruption of

circuits carrying large currents for short times can be accurately controlled was the next subject. In a relatively small tube a current of 30,000 amperes was discharged for one millionth of a second and resulted in radiation of strong visible light waves. In a darkened room a rubber ball shot at high velocity broke a control wire which discharged the tube. Because of the extremely short duration of the flash and the persistence of vision, the ball could be seen for an instant apparently standing still in front of the tube.

The paper was finished with a demonstration of an infrared burglar alarm system. The infrared light being invisible, no evidence is given an intruder of having operated the alarm system.

Two meetings of the Buffalo-Niagara Section were held in April. The first was on the 21st at the University of Buffalo and was attended by fifty. Karl Hoffman, vice chairman, presided and a paper on "High-Frequency Broad-Band Wire Transmission Systems" was presented by E. I. Green of Bell Telephone Laboratories, Inc.

The use of the term "broad-band" is relative and may have different meanings as one goes from wire line circuits to radio. In wire lines transmission speeds are slower than in radio and in cable circuits transmission speeds as low as 10,000 to 20,000 miles per second are encountered. These may produce echoes and require transmission times of a substantial fraction of a second in long lines. The characteristics of open wire lines, cables, and coaxial cables were shown. Developmental problems concerning amplification and stability were described briefly and the limitations of present equipment indicated.

A description was given of developments in the transmission of high frequencies over open wire lines, cables, and coaxial structures. The use of amplifiers to compensate for attenuation on lines was described. In some cases they are located only about ten miles apart and have complex regulating arrangements to compensate for changes in temperature and weather on the conductor characteristics. The band of frequencies transmitted can be subdivided by filters to provide multiple communication channels or the entire band may be used for such purposes as television. As an example of the effect of the wave band transmitted, slides illustrating the fineness of definition of transmitted television pictures using bands as wide as eight million cycles were shown. It was pointed out that the broad-band transmission technique was made possible by extremely stable feed-back amplifiers, crystal filters, and similar devices.

The paper was closed with a description of a twelve-channel carrier system for open wire lines, a similar system for application to existing

cables, and a million-cycle, 240-channel coaxial system which may be used for high definition television.

The April 24 meeting took the form of a trip through the new Buffalo Police Headquarters and the radio station. There were twelve present. The trip included an inspection tour of the headquarters station, the bureau of identification with its finger-printing and photographic equipment, the pistol range, and all communication rooms for telephone, telegraph, signal, and teletype circuits. Just outside the building there was demonstrated a two-way conversation involving an installation in a patrol car and the central station located five miles away. Although almost 100 cars are equipped with a radio, only four now have two-way apparatus.

The group then motored to the police radio station. Its equipment was first described. The system permits the operator to communicate either by wire or radio to all cars and police stations using telephone or telegraph transmission. Much of the equipment is provided in duplicate and numerous switching arrangements permit rapid substitution of equipment under emergency conditions. The equipment was described by Lawrence Geno who is in charge of the station.

Chicago Section

A paper on "Electronic Music" by Alfred Crossley, consulting engineer, was presented at the March 19 meeting of the Chicago Section which was held in the Hotel LaSalle. J. K. Johnson, chairman, presided and there were 111 present.

Mr. Crossley reviewed the history of musical instruments and described the mechanism of the Everett Organtron and several other electronic instruments. After the paper was delivered, a group visited the studios of Lyon and Healy where the Everett and Hammond organs were demonstrated.

The April 23 meeting of the Chicago Section was attended by 102 and held in the Hotel LaSalle with Chairman Johnson presiding.

S. M. Richie, in charge of the U. S. Department of Commerce Airways Radio Laboratory in Chicago, presented a paper, "Current Developments in Radio Aids to Air Navigation." He described the present radio range stations operated by the Department of Commerce and the conversion of these stations to permit simultaneous operation of the radio range system and weather broadcasts. He described also the ultra-high-frequency vertical beam marker beacons which are being developed to indicate to a plane pilot when he passes directly over a range station.

Cincinnati Section

Two meetings of the Cincinnati Section were held in April. The April 2 meeting was held jointly with a number of other engineering societies in the Taft Auditorium and was attended by 3000. A paper entitled "Waves, Words, and Wires" was presented by F. A. Cowan, engineer of transmission of the American Telephone and Telegraph Company. The paper was originally scheduled to be presented by J. O. Perrine of Bell Telephone Laboratories who was prevented from being present by illness.

A three-channel audio public address system was used to demonstrate the effect of restricting the band of frequencies. By suitable filters, the effect of restricted bands on both speech and music was demonstrated. The effect on hearing of the power level was then indicated by starting at zero reference level and increasing the output to a value of plus sixty decibels. The quality of transmission obtainable over two circuits each 2000 miles long was then demonstrated to illustrate the effects of mismatching impedances. Such undesirable mismatches were purposely introduced and the distortion, line noise, and echoes resulting were demonstrated.

The April 27 meeting was attended by 105 and was held at Wright Field, Dayton, Ohio. G. F. Platts, chairman, presided.

A paper on "Communications in a Modern Army" was the subject of a paper by J. O. Mauborgne, director of the Aircraft Radio Laboratory. Colonel Mauborgne presented a picture of the communication requirements of the Army. He showed how radio is used in an army division to keep in touch with mechanized troops, battalion headquarters, artillery support, and aviation observers. The use of portable transceivers for contact with reconnaissance parties and individual scouts was illustrated. A light portable teletypewriter was displayed and makes possible transmission of information at fairly good speed even by inexperienced personnel. He closed his paper with an illustration of the use of radio in the blind landing of airplanes.

The second paper on "Novel Methods of Testing Aircraft Radio Compass" was presented by R. J. Framme, a research engineer at the Aircraft Radio Laboratories. It is necessary to test aircraft radio compasses in the laboratory. The compass is placed in the center of a large shielded room. Across the room at a predetermined height a wire is stretched for a transmission line and terminated by a matching impedance. A signal generator is connected to the other end. The field strength at the center of the compass loop is calculated by taking into account three factors for any fixed position of the loop and line. These are the reflection constant, generator constant, and frequency constant.

Cleveland Section

The March meeting of the Cleveland Section was held on the 18th at Case School of Applied Science and presided over by R. A. Fox, chairman. There were twenty-four present.

A paper on "Feed-Back Audio-Frequency Amplifiers" was the subject of a paper by E. K. Ackerman, amplifier design engineer of Radio Air Service. It covered problems involved in a particular type of feed-back amplifier designed for remote pickup. Particular emphasis was made on the use of bridge type feed-back networks in order to achieve a uniform degree of feedback in relation to frequency. The paper was discussed by Messrs. Gove, Leonard, and Smith.

"Two-Terminal Equalizers" was the subject of a second paper which was presented by C. E. Smith, assistant chief engineer of WHK-WJAY. It was pointed out that two-terminal equalizers of either the series or shunt variety were the simplest forms of attenuation equalizers. Design considerations and formulas in the development of both the series admittance and shunt impedance types were given. A discussion was then given of constant reactance equalizers and T-section, shunt T-section, and lattice networks were covered. It was emphasized that the lattice network is the most flexible and should be employed in permanent installations. The paper was discussed by Messrs. Hamman and Pierce.

On April 28 the Cleveland Section met in the WHK Studios with Chairman Fox presiding. There were twenty-three present.

"Recent Improvements in Crystal Pickup Devices" was the subject of a paper by J. R. Bird, engineer for Astatic Microphone Laboratories. The response versus frequency characteristic of a crystal pickup was stated to be the reverse of a crystal microphone in that maximum response is obtained at the lower frequency end of the spectrum. Particular emphasis was laid on the improved tracking obtained with an offset crystal head. Tracking error can be reduced with a $10\frac{1}{4}$-inch arm to a maximum of $1\frac{1}{2}$ degrees and with a 12-inch arm to a maximum of 2.4 degrees with an offset head as against the maximum, with an 8-inch straight arm of as high as 22 degrees. Tracking error was defined as the angle between the tangent to the record groove at the point of needle contact and the needle itself projected into the plane of the record. Tracking error results in several undesirable effects, chiefly represented by more rapid record wear and wave-form distortion. Accurate tracking results in longer record life, higher fidelity, and also a reduction in surface noise due to a lessening of the side pressure on the needle. Various forms of mechanical couplings between the needle chuck and the crystal were discussed.

In the discussion of the paper which was participated in by Messrs. Leonard, Makinson, Pierce, Smith, and Weiss, it was pointed out that a Rochelle salt crystal shunted by a resistance in excess of ten megohms behaves as a pure capacitance up to its resonant point beyond which it acts as a pure resistance.

Connecticut Valley Section

F. H. Scheer, chairman, presided at the March 25 meeting of the Connecticut Valley Section held in the Hartford Electric Light Company auditorium. There were twenty-seven present.

H. S. Knowles, chief engineer of the Jensen Radio Manufacturing Company presented a paper on "Extending the Audio Range of Loud-Speakers." He pointed out that the trend in the last two years of radio receiver design has made necessary improved low-frequency response. Electrical methods of bass compensation produce desirable results on musical programs but fall short in that they reduce the intelligibility of speech. It has been necessary, therefore, to attack the problem from the acoustic angle. He then discussed methods used in the treatment of radio cabinets to improve low-frequency response. The method described in detail employs a tuned acoustic transmission line coupled to the rear of the speaker. Its dimensions are such that the desired frequencies leave a port inphase with the waves from the front of the speaker diaphragm. Typical cabinets so treated were shown and the performance of speakers under these conditions indicated by graphs.

Detroit Section

The March 19 meeting of the Detroit Section which was attended by sixty-two was held in the Detroit News Conference Room and presided over by R. L. Davis, chairman.

F. S. Kaserman, engineer-in-charge, and H. D. Seilsted, engineer, of the U. S. Lighthouse Service presented a paper on "Radio Activities in the U. S. Lighthouse Service." Mr. Kaserman gave an outline of the history and some of the traditions of the Lighthouse Service and the use and development of radio in it up to the present time. Mr. Seilsted then described equipment now being used in the remote control of apparatus located on lightships. The meeting was then adjourned to the laboratories of the Lighthouse Service where an inspection of the shops was made and the equipment described was demonstrated. From there members were taken abroad lightships and tenders which were in port at the time for further inspection.

Unattended lightships are operated at the present time on which all equipment including radio beacons, power supply generators, lights,

and clocks are remotely controlled either from shore or attended lightships several miles away.

Control of the equipment is accomplished by transmitting a carrier modulated by a 700-cycle note. The tone operates a tuned reed relay in the plate circuit of the detector tube of the ship receiver which in turn operates a sequence switch through a time delay relay. All of the equipment on the ship may be controlled in this manner.

The April meeting of the Detroit Section was held on the 16th in the Detroit News Conference Room and attended by forty-five. Chairman Davis presided.

G. V. Peck of the P. R. Mallory Company presented a paper on "Capacitor Requirement Analysis." It was pointed out that electrolytic condensers employ as dielectrics a thin coating of oxide formed directly on one of the plates while the second "plate" is the electrolyte which in the usual dry type condenser is in the form of a paste. The gauze or paper which separates the plates of an electrolytic condenser is used only to carry the paste and to prevent the two metal foils from touching. The voltage at which the oxide coating breaks down is determined by the voltage used during the formation of the plates. Voltages up to six hundred may be used in forming the plates. The highest voltage rating of the condenser is determined by the voltage at which the paste electrolyte breaks down. This is about 525 volts and is the highest voltage at which the ordinary condensers are rated. The plates are formed prior to the assembly of the unit. Capacitance may be increased about four times by etching the plates and thus enlarging the area of active surface.

Breakdown of electrolytic condensers is usually caused by the collection of hydrogen gas on the anode. Any sparking at the plate thereafter causes this gas to unite with oxygen and the resulting minute explosion damages the condenser mechanically. Leakage current through the condenser increases with temperature, rising sharply above certain critical values. The increased current causes higher temperatures which increase the effect.

Electrolytic condensers are being used widely for condenser-start single-phase motors. These condensers are similar to direct-current condensers except that two positive plates are used. They are in effect two direct-current electrolytic condensers connected back to back. The operation of each condenser in a reverse direction on alternate halves of the cycle is not harmful. The power factor of this type of condenser varies from two and a half to seven per cent.

EMPORIUM SECTION

A meeting of the Emporium Section was held on March 11 at the American Legion Club Rooms with M. I. Kahl, chairman, presiding. There were fifty present.

P. Robinson of the Sprague Specialities Company presented a paper on "Electrolytic Capacitors and Their Applications." Dr. Robinson pointed out that an electrolytic condenser may be considered as two parts, the anode and the cathode, each section having a capacitance of its own and being connected in series to give the capacitance of the unit. The constructional difference between dry and wet electrolytic condensers was pointed out.

He then presented a mathematical discussion on the charging rate, maximum current, and power factor in condensers. In general there are two types of charging curves, one of which starts at a high value and drops off quite rapidly and the other which starts out with the same value and drops off less rapidly ending with a higher minimum value of current. This latter condition was shown to be valuable in filter circuits when used in the second section as a regulating type condenser by protecting both the first section filter condenser and the rectifier tube. Numerous field problems and methods of treating materials to gain specific characteristics were then discussed. Illustrations were given to show the cathode surfaces under various conditions. The paper was discussed by Messrs. Bachman, Baldwin, Bowie, Jones, West, and Wise.

R. H. Langley, consulting engineer, presented a paper on "Some Studies of Magnetic Materials at High Frequencies" at the April 1 meeting of the Emporium Section which was held in the American Legion Club Rooms. There were forty-two present and Chairman Kahl presided.

Mr. Langley opened his talk by quoting from a U. S. Patent applied for in 1886 describing the first powdered iron cores for use in alternating-current circuits. The remarkable thing about the patent is that, although written fifty-one years ago, it describes practically every problem in iron-core design. He then showed how the inductance and radio-frequency resistance varied by inserting an iron core in a radio-frequency coil. It was pointed out how a higher Q could be obtained with an iron-core coil than with an air-core coil having the same inductance. Some mathematical solutions were then given to determine the radio-frequency resistance at any frequency for a given coil. This was supplemented by a simple method to determine the same thing in the

form of an empirical equation. In concluding the paper a demonstration was given of a model of the Chaffee analogue of coupled circuits.

There were forty-four present at the April 23 meeting of the Emporium Section which was held in the American Legion Club Rooms and presided over by Chairman Kahl.

"A Basis for Vacuum Tube Design" was the subject of a paper by M. A. Acheson of the Hygrade Sylvania Corporation. It was pointed out that by the invention of basic units for the expression of vacuum tube dimensional relations and the proper syntheses of these units, rigorous calculation of vacuum tube design and performance could be obtained. These calculations are of simpler form than those where solutions by present methods can be had and often allow solutions where they are not available at the present time. These units and their syntheses are of such a nature that logical trends in design can be followed in many cases entirely aside from the formulas into which they enter. Two exemplary problems were then solved, that of minimizing microphonics and that of designing tubes for least random variation from desired characteristics. The paper was discussed by Messrs. Campbell, Carter, Espersen, Fink, Hoffman, Kievit, Steen, and Wise.

Los Angeles Section

V. O. Knudsen, chairman of the physics department and dean of the graduate school of the University of California presented a paper on "Architectural Acoustics and Acoustics of Broadcast Studios" at the February 16 meeting of the Los Angeles Section. The meeting was held in the Los Angeles Junior College, presided over by Douglas Kennedy, chairman, and attended by forty-two.

Dr. Knudsen pointed out that considerable advancement in the subject of acoustics has been and is being made in foreign countries such as Germany, England, Italy, and Japan. Among individuals particularly active are Cremer, Bikesy, and Meyer. An important contribution has been the design of absorption vibrating diaphragms with large effective absorption coefficients at low frequencies. This property is difficult to obtain with ordinary absorbing materials.

New York Meeting

Two papers were presented at the April 7 New York meeting of the Institute which was presided over by President Beverage. The meeting was held in the Engineering Societies Building and attended by 400.

The first paper by S. D. Browning of the Federal Telegraph Company described the "Mackay Radio and Telegraph Company Auto Alarm Type 101-A". It was pointed out that the Federal Com-

munications Commission has issued requirements and type tests for an auto alarm intended for use on vessels to receive the international auto alarm distress signal and operate alarm bells on that vessel. The device described in this paper was developed to fulfill these requirements and has passed the Commission's tests and received approval. Events leading up to the development of the equipment and discussion of the requirements that must be met by such a device were covered. The system was described in detail and the method of operation outlined.

The second paper on "The Practical Application of an Ultra-High-Frequency Relay Circuit" was presented by J. E. Smith of the RCA Communications, Inc. In it the utilization of an ultra-high-frequency radio circuit for the transmission of telegraph, teletype printer, and facsimile signals was described. The operating procedure was outlined particularly with regard to test methods to determine the conditions of the circuit such as the degree of modulation, signal-to-noise ratio, etc. Considerations were presented with respect to the most efficient division of the total modulation band into communication channels as well as the signal-to-noise ratios required for the different types of service. Fading, static, and weather conditions at these frequencies are of little importance in their effect on the economic use of the circuit. However, diathermy machines and similar types of interference must be minimized. Experience during the past year indicates that the dependability of the ultra-high-frequency radio circuit is of a high order. A demonstration of the Philadelphia-New York radio relay circuit was given and it was operated for both printer and facsimile services.

Philadelphia Section

The Philadelphia Section held its April 1 meeting jointly with the Franklin Institute in the building of that organization. Dr. Barnes, chairman of the Franklin Institute, presided and there were 350 present.

A paper on "Magnetic Materials and their Application to Loud-Speaker Design" was the subject of a paper by L. B. Conwell, chief engineer of the Cinaudagraph Corporation. He presented a detailed description of the use of nipermag, a permanent magnet alloy developed in Europe by Alfred Catherall. The alloy is extremely hard and can only be formed by casting. It must be carefully heat-treated to secure its greatest magnetic possibilities. Its specific gravity is seven which is twelve per cent lighter than the cobalt steel magnetic alloy. Important features in the design of magnetic circuits were described. The use of a magnetic material of high coercive force allows a magnet to be made

relatively short between poles and will reduce the leakage and amount of material required. A B–H demagnetization curve of nipermag showed the high value of 660 oersteds of coercive force and a remanance of 5000 gausses. A derived curve showed for H at B–H maximum a value of 375 gilberts per centimeter and for B at H maximum 2750 gausses.

It is advantageous to make the air gap in loud-speaker field magnets as narrow as possible. By winding the voice coil on a mica bushing the space required is reduced and the coil structure is firm and strong. Field intensities equal to or greater than those obtained with electromagnetic fields were claimed. The paper was closed with a demonstration of nine-inch and eighteen-inch loud-speakers employing permanent field magnets.

Pittsburgh Section

The four following reports cover meetings of the Pittsburgh Section which were held at the Carnegie Institute of Technology. The first three were presided over by B. Lazich, chairman, and the last by R. T. Gabler, vice chairman. The attendance at each meeting was approximately thirty.

At the January 19 meeting, W. R. Jones, commercial engineer for the Hygrade Sylvania Corporation presented a paper on "Audio Amplifiers." The various troubles which may be experienced because of faulty choice of circuit constants, stray capacitance, parasitic oscillations, incorrect voltage, etc., were discussed. Special interest was shown in the 6Q7, a duodiode high-mu triode and the 6L6 beam power tube. It was pointed out that these tubes perform well when the fundamental requirements of good circuit design are followed. The paper was discussed by Messrs. Gabler, Hobson, Krause, Place, Miller, and Stark.

W. O. Osbon, research engineer for the Westinghouse Electric and Manufacturing Company presented a paper on "Negative Feed-Back Amplifiers" at the February 16 meeting. He developed the regenerative or feed-back theory and showed that when certain conditions were met the gain of the amplifier was independent of all factors except the amount of negative feedback. Hints on successful design and a description of some amplifiers were given. The paper was discussed by Messrs. Lazich, Krause, Miller, Muffly, and Place.

R. T. Griffith, transmission engineer for the Bell Telephone Company of Pennsylvania, on March 16 presented a paper on "High-Frequency Telephone Systems." He presented first a historical sketch of

telephone development beginning with Bell's earliest experiments and terminating with a discussion of the recent coaxial cable installation between New York and Philadelphia. It was pointed out that single side-band transmission, good amplifiers, and sharp cutoff filters have made multichannel telephony over long distances possible. Amplifiers to make up for line losses are spaced every few miles and the total amplification, especially when using carefully designed negative feedback amplifiers as are employed with the coaxial cable, run into astronomical figures for coast-to-coast telephony. The paper was discussed by Messrs. Adams, Bossart, Drabik, Findley, Gabler, Hoyt, Krause, Lazich, Pickels, Place, Shuey, Stark, and Sutherlin.

At the April 20 meeting a paper on "Development of Direct Reading Methods" was presented by R. F. Field, engineer for the General Radio Company. He first pointed out that meters must be built with nearly permanent characteristics in order to justify a direct reading scale and discussed some of the problems involved. Following this he showed illustrations of a number of different kinds of instruments and described the particular uses of each. Some instruments performed a number of functions with reasonable accuracy while others such as precision variable air condensers performed only one function with great accuracy. The paper was discussed by Messrs. Crooks, Gabler, Muffly, Stark, and Work.

San Francisco Section

Two meetings of the San Francisco Section were held during March, the first on the 17th was in the Hotel Bellevue and was attended by eighty-six. V. C. Freiermuth, chairman, presided.

A. E. Thiessen of the General Radio Company showed two reels of motion pictures illustrating uses of the Edgerton stroboscope. This was followed by a paper on "Direct Reading Instruments." A number of those present participated in the general discussion.

The second meeting on the 24th was held jointly with the local section of the American Institute of Electrical Engineers at the San Francisco Engineers Club and was presided over by Howard Lane, chairman of the A.I.E.E. section, and attended by 130.

A paper on "Acoustics of Buildings" was presented by V. O. Knudsen, professor of physics at the University of California. Dr. Knudsen briefly covered the fundamental considerations in the design of buildings to result in their having desirable acoustic properties. Mistakes in some of the older buildings were described and methods of correcting

them outlined. He presented some detailed information on the making of acoustical measurements and pointed out how it was possible to get at a distance by radio the reverberation constant for a hall in which an orchestra is playing.

Seattle Section

On March 26 a meeting of the Seattle Section was held at the University of Washington with J. W. Wallace, chairman, presiding. There were eighty present.

H. M. Hucke, chief of the United Air Lines laboratories at Chicago presented a paper on "The Communications Systems and Radio Research of United Air Lines." In it he described the various types of communication facilities and their operation and maintenance by United Air Lines on its 5000 miles of airways. Thirty-one ground radiotelephone stations utilizing 400-watt transmitters are located along the airways at intervals of 150 to 200 miles for communication with planes. A day and a night frequency between five and ten megacycles are assigned to each station. All transmitting and receiving equipment utilize crystal controlled oscillators. Because of severe vibration on the planes unusual problems of design and maintenance have been encountered. Sets are designed to be readily removable from planes thus permitting all maintenance to be done in the shop. The radio beacon system and the functions of the teletype and commercial telegraph and telephone services in the airways operations were also described.

Tests and observations which are now being made during special flights between Salt Lake City, Utah, and Portland, Oregon, for the purpose of studying snow static were also described. Higher speeds of transport planes have increased materially the static caused by moving through clouds of ice crystals which are often present at high altitudes. Static is worst in cold dry air, somewhat less when passing through snow and least when passing through rain. Its intensity increases with the speed of the plane and is often accompanied by a corona about the propeller. This work is being carried on by a group of ten engineers in a specially equipped plane and has not progressed sufficiently to permit a statement of the results to be made. The paper was discussed by Messrs. Hurlbut, Renfro, Smith, and Walker.

Chairman Wallace presided at the April 30 meeting of the Seattle Section which was held at the University of Washington. There were thirty-eight present.

"The Metallo Probe" was the subject of a paper presented by G. K.

Barger of the Washington State Highway Department. It is an electronic device developed by the author for studying the cause of unexpected fractures in new concrete highways. So-called "dummy" joints are placed in concrete highways at frequency intervals. This separation between adjacent sections extends only to a depth of about two inches. Below this seam, steel dowel bars an inch in diameter and two inches long are placed longitudinally to join the sections. When the concrete sets, a fracture occurs through the seam because of its smaller cross section and thereby relieves the stresses. The dowel bars hold the adjacent sections in alignment. The appearance of undesired fractures through the main section of concrete near the seams resulted in the need for the development of this equipment. It consists of a bridge circuit containing two exploring coils and a balanced detector. As the concrete was found to be magnetic, it was necessary to introduce a phasing potential into the detector to neutralize the affects of the homogenous mass of concrete. When properly adjusted, the equipment gives a measure of the increase in eddy currents caused by the dowel bars being in the field of the exploring currents. Deviations in the vertical and horizontal alignments of the bar can be measured to within one-half inch. Sticking of the bars to the concrete and deviations from the horizontal and vertical axes were found to be the causes of the undesired fractures. Messrs. Dammon, Scott, Walker, Wallace, and Wilson participated in the discussion.

Toronto Section

The following three reports are on meetings of the Toronto Section which were held at the University of Toronto and presided over by B. deF. Bayly, chairman. The attendance at these meetings was seventy-seven, seventy-eight, and 104, respectively.

"Recent Advances in Measuring Instruments as Applied to the Field of Radio" was the subject of a paper by J. H. Miller, assistant chief engineer of the Weston Electrical Instrument Corporation, which was presented at the meeting on January 25. He presented first the history of electrical instruments and the development of radio testing equipment from the first simple voltmeter to present-day apparatus capable of practically any type of measurement. Many test equipments are awkward to operate and involve many switching operations or their equivalent. The present trend is to simplify the instruments so that usefulness, accuracy, ruggedness, and speed of operation are obtainable. Accuracy of instruments was discussed and various methods of ensuring it and ruggedness were explained.

J. R. Warren of the Canadian Westinghouse Company Limited presented at the February 22 meeting a paper on "Radio Tube Applications." The speaker pointed out the remarkably large number of different types of vacuum tubes now being produced, and then confined his paper to several specific applications of some of the later types. The 6J7 tube as applied to automatic tuning circuits was described in detail. The operation of the various components and how operating and control voltages were obtained were described. Phase relations between different parts of the circuit were explained and a method of obtaining the desired relations necessary to control the tuning mechanism were covered. The 6L6 tube was described. It has a rising high-frequency characteristic which may be compensated for in the receiver circuit. It is capable of high output over a wide frequency range. A special circuit in which a pentode controls the damping of the loud-speaker cone was shown. This permits the distortion caused by the inertia of the loud-speaker cone to be eliminated. The intricacies of construction of present-day vacuum tubes was indicated by a selection of mounts examined by those present.

On March 22, N. J. Matheson of the Canadian Marconi Company presented a paper on "The Blattnerphone." After outlining the history and development of the device it was described as comprising a steel tape one tenth of an inch wide and three and one quarter thousandths of an inch thick. The tape is run between pole pieces of the recording and reproducing heads by means of synchronous motor drives. It must, therefore, pass these heads at a constant rate of speed and various types of drives to accomplish this were described. The tape is of Swedish steel having particular characteristics for recording and reproduction by means of its magnetic properties. A hysteresis loop was shown and the points on the loop marked to show the way in which the steel was magnetized in order to get good reproduction. The field from the recording head pole pieces in passing through the tape produces a permanent longitudinal flux which varies in strength with the signal passing through the recording head winding. As the tape is moving at a constant rate this gives a record of the signal when the reproduced head is connected to the amplifier. The paper was closed with a demonstration of the device. Frequencies between fifty cycles and 9000 cycles are reproduced. A number of those present recorded their voices which were immediately compared with the original speech. About two miles of tape are required to record the usual half-hour program and storage vaults at Ottawa contain many famous broadcasts which are available for future use.

Washington Section

On March 12 the Washington Section met at the Potomac Electric Power Company auditorium. W. B. Burgess, chairman, presided and there were 110 present.

"A New High Efficiency Amplifier for Modulated Waves" was the subject of a paper by W. H. Doherty, engineer for the Bell Telephone Laboratories. The presentation was based on the contents of a paper under the same title which appeared in the September, 1936, issue of the Proceedings. It was concluded with a demonstration employing a cathode-ray oscilloscope by means of which the phenomena discussed were clearly shown.

On April 12 the Washington Section met at the Potomac Electric Power Company auditorium with Chairman Burgess presiding. Forty-five were present.

J. H. Dellinger, chief of the Radio Section of the National Bureau of Standards, presented a paper on "Anomalies in High-Frequency Radio Transmission." The paper included discussions of magnetic storm effects, sudden fade-outs, and anomalous intensities of transmission over different fields. Recordings made at the Bureau of Standards and at other observation points were used to show the relationship of the above phenomena to the cyclic changes in the earth's magnetic field and the occurrence of sunspots. The paper was discussed by Messrs. Dingley, Kirby, and Wheeler.

Personal Mention

B. E. Atwood, formerly with United American Bosch Corporation, has joined the staff of Colonial Radio Corporation at Buffalo, N. Y.

W. T. Buhl, previously with P. R. Mallory and Company is now a physicist with the Physicists Research Company of Ann Arbor, Mich.

E. L. Johnston is now a quality standards engineer with the Western Electric Company at Chicago, Ill., having formerly been a radio engineer at the University of North Dakota.

L. W. Olander has left the RCA Manufacturing Company to become chief engineer of the E. F. Johnson Company, at Waseca, Minn.

Wayne Miller is now transmitter research engineer with First National Television, Inc., Kansas City, Mo., having previously been with the RCA Manufacturing Company.

A. E. Rodriguez is now with the Zenith Radio Corporation, Chicago Ill., having left the North Shore X-Ray Laboratory.

E. E. Schwarzenbach who was formerly with the Case Electric

Corporation is now on the engineering staff of P. R. Mallory and Company, Indianapolis, Ind.

M. P. Wilder formerly with the RCA Manufacturing Company, has joined the engineering staff of the National Union Radio Tube Company, Newark, N. J.

H. T. Winchel formerly with Solar Aircraft is now a radio engineer for Eastern Airlines at Miami Springs, Fla.

Correction

Charles B. Aiken has brought to the attention of the editors the following typographical errors which appeared in his paper "Two-Mesh Tuned Coupled Circuit Filters," published in the February, 1937, issue of the PROCEEDINGS.

Page 236

Line 21 $\cdots X_m$ should read Z_m.

Lines 23 and 24 $\cdots Z_m$ should be struck out of the definitions of Z_1 and Z_2.

Page 242

Equation (25) $\cdots 1/2\pi L$ should read $(1/2\pi L)$.

Page 252

The second equation in the line above (66) should read $L_1/C_1 \neq L_2/C_2$.

Page 268

Three lines from the bottom, "unity" is misspelled.

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TECHNICAL PAPERS

THE SHUNT-EXCITED ANTENNA*

By
J. F. Morrison and P. H. Smith
(Bell Telephone Laboratories, Inc., New York, N. Y.)

Summary—*The paper describes an arrangement for exciting a vertical broadcast antenna with the base grounded. Construction economy results through the elimination of the base insulator, the tower lighting chokes, and the usual lightning protective devices. The coupling apparatus at the antenna end of the transmission line is reduced to an extent which may make unnecessary a separate building for its protection. Greater freedom from interruptions resulting from static discharges is expected. The performance of the design is substantially the same as that obtained from the antennas now in general use.*

The paper describes experimental work done, results obtained, and inferences to be drawn from them. A mathematical appendix is attached.

Introduction

THE advances in broadcast antenna design made during the last decade have been primarily directed toward increasing the intensity of radiation at the ground level with a concurrent reduction in the intensity at elevations above the ground. The reasons which make this form of distribution desirable and the advances made in that direction are well known to the radio engineer, so that it is not necessary here to emphasize the importance of continued work toward that objective. However, the concentration of thought on the radiation characteristics has distracted attention from a consideration of the many other problems that are associated with the present design practice.

Antennas such as are used for broadcasting are connected at the base through the generator or coupling impedance to ground, and it is generally understood that the coupling impedance as viewed from the antenna in no way affects the radiation characteristics of the antenna. In fact, as far as the radiation characteristics are concerned, the antenna may be connected directly to ground without affecting its performance. It might at first appear difficult to couple power efficiently into a vertical antenna grounded at its base, particularly at frequencies other than the resonant frequency of the antenna. However, considera-

* Decimal classification: R320. Original manuscript received by the Institute June 15, 1936. Presented before Eleventh Annual Convention, Cleveland, Ohio, May 13, 1936.

tion of the problem will indicate that this can be accomplished by using a very small portion of the antenna, at its base, as a coupling impedance. The impedance across this coupling section may then be transformed to the characteristic impedance of a concentric transmission line by an inclined conductor and series capacitance. A sketch of the shunt-excited antenna, series capacitance and concentric transmission line is shown in Fig. 1.

The advantages afforded by the shunt-excited antenna are immediately evident. In the first place, antenna structure cost is less since no base insulators are required and the more rigid support which can be provided at the base permits the use of smaller cross-sectional

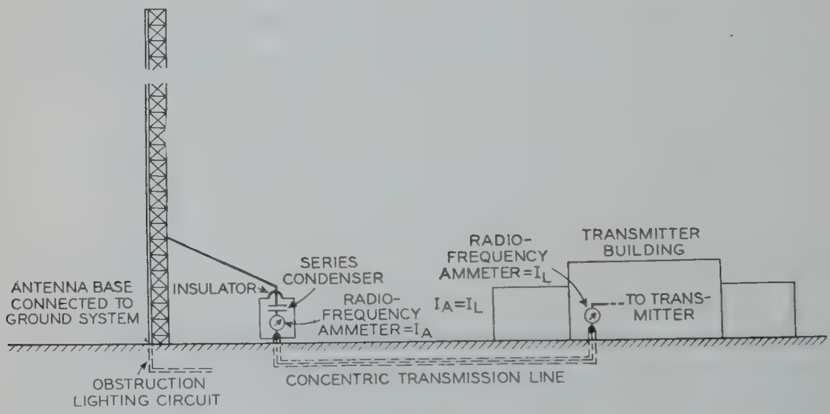

Fig. 1—Coupling arrangement for the shunt-excited antenna.

dimensions in the case of the self-supporting type vertical radiators. Filter devices for obstruction light circuits are not required and the circuits may be run directly to the antenna base and thence vertically up the antenna structure. Difficulties caused by lightning are reduced and the need for static drain devices is eliminated. The resistance of the radiating system is permanently adjusted, by methods described later, to equal the characteristic impedance of a transmission line. This feature eliminates the need for coupling transformers and also makes possible a standardization of antenna current meter scales for all installations using the same type of transmission line. When the transmission line is correctly terminated by the resistance of the radiating system and a series resonating capacitance, the current reading at the sending, or transmitter end of the line is a direct indication of the current entering the radiating system, as the losses in well-designed lines are negligible at broadcast frequencies. The hazards of contact

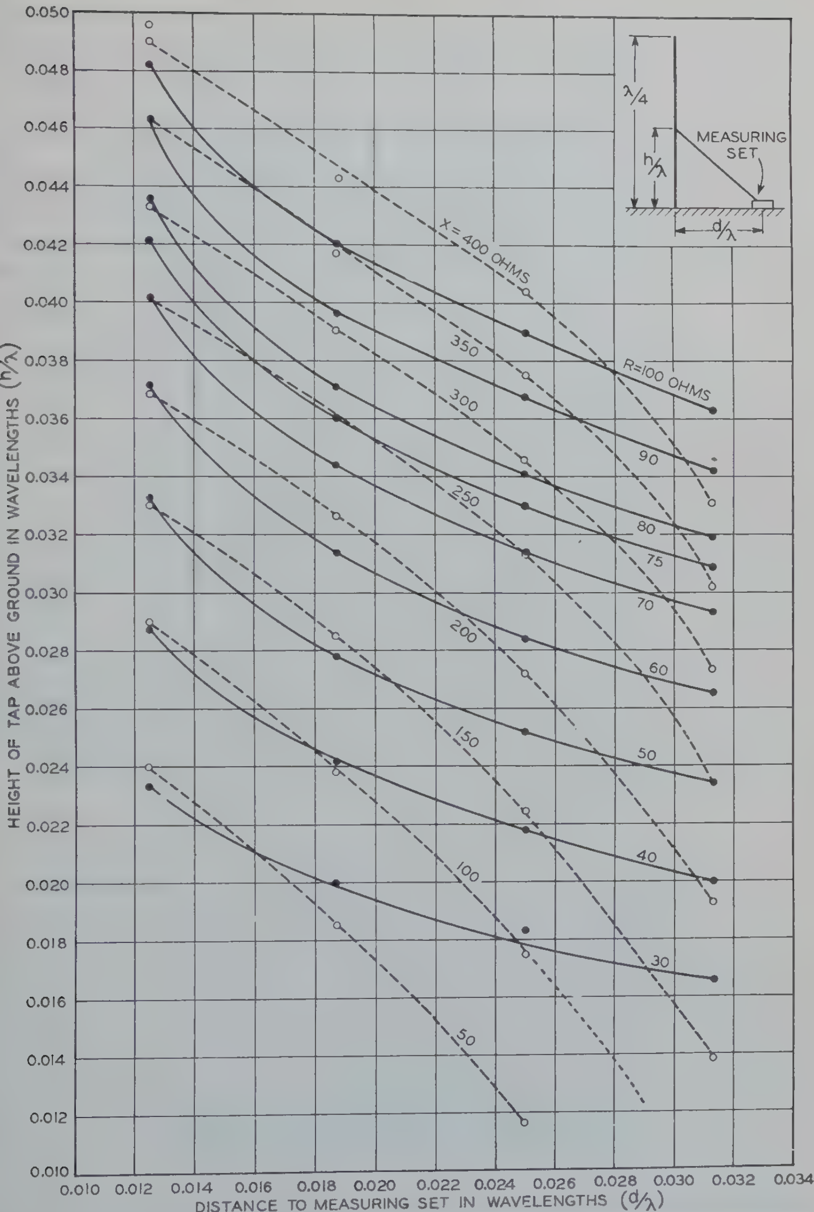

Fig. 2—Resistance and reactance of a four-inch diameter shunt-excited antenna.

with high voltages which exist with insulated structures are removed since the base of the structure is at ground potential.

Fig. 2 was prepared from impedance data taken on an experimental antenna 200 feet high and four inches in diameter. This figure shows the resistance and reactance at the base of the inclined conductor as a function of the coupling section height and distance to the base of the vertical structure, when the system was operated at the resonant frequency of the antenna. Resistance values less than 100 ohms which are generally required to match a concentric type transmission line were obtained when the inclined conductor was at an angle of about 45 degrees and the sides of the triangle thus formed were less than 0.035 wave length long. It will be noted that the sign of the reactance at the base of the inclined conductor is always positive so that it is only necessary to use a series condenser to adjust the antenna impedance to unity power factor.

The results obtained with the experimental antenna were sufficiently encouraging to justify the continuance of the investigation with an antenna having physical dimensions that might commonly be used in practice. The work was conducted at Detroit, Michigan, where through the courtesy of the *Detroit Daily News* a 400-foot Blaw Knox uniform cross-section vertical radiator at station WWJ was made available. Fig. 3 is a photograph of this radiator. It is six feet, six inches square throughout the entire height except for the lower 22 feet which tapers to the dimensions of a single conical porcelain insulator. Since this radiator is insulated from ground it provided the opportunity of studying its performance when either series or shunt-excited for comparison purposes.

Impedance at the Base of Insulated Antennas

A study of the impedance at the base of the insulated antenna was made in order to determine the antenna input power during field intensity tests and to obtain information which would be useful in the study of the shunt-excited antenna. The measured resistance and reactance are shown on Fig. 4 plotted as a function of the antenna height in wave lengths. It will be noted from these data that the antiresonant frequency (as defined by unity power factor at the base) occurred at an antenna height of 0.425 wave length instead of 0.5 wave length which might be expected from transmission line theory of a uniform lossless line.

Since the capacitance of the base insulator was shunted across the measuring device it would be expected to affect the impedance data. However, in the case of the antenna studied the capacitance of the base insulator was about 30 micromicrofarads and at the frequencies used its effect upon the data was slight.

The data shown on Fig. 4 are replotted on Fig. 5 as a series of impedance vectors, thus combining resistance and reactance on a single

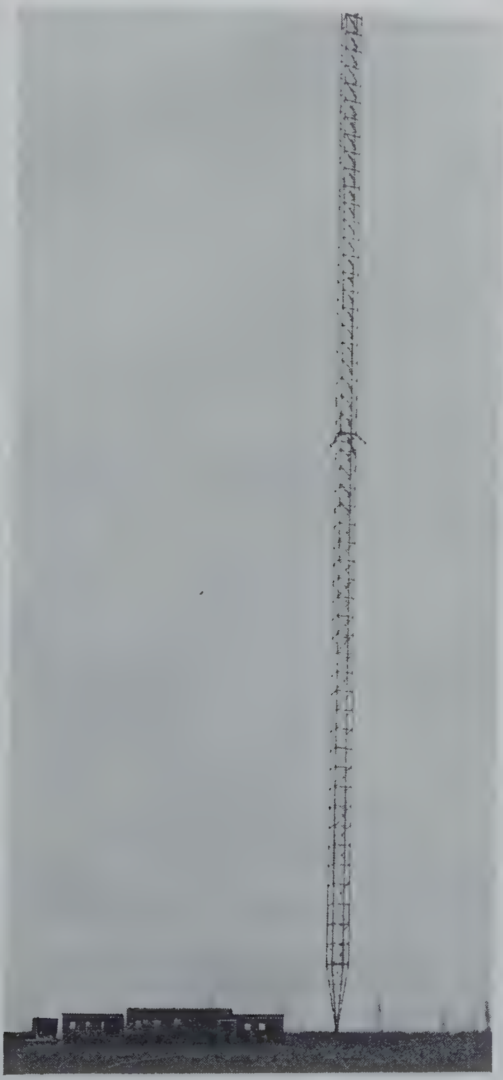

Fig. 3—The uniform cross-section vertical radiator at station WWJ.

plot. In this manner of depicting the data, a curve which connects the points represents their locus as the frequency is varied. Irregularities in the data which are not evident from separate resistance and reactance

curves are more readily observed and a better check upon the accuracy of the impedance measurements is provided. The solid curve represents a locus of the calculated impedances based upon a transmission line formula for a line with distributed losses.[1] The equations used for computing this locus curve are given in Appendix I.

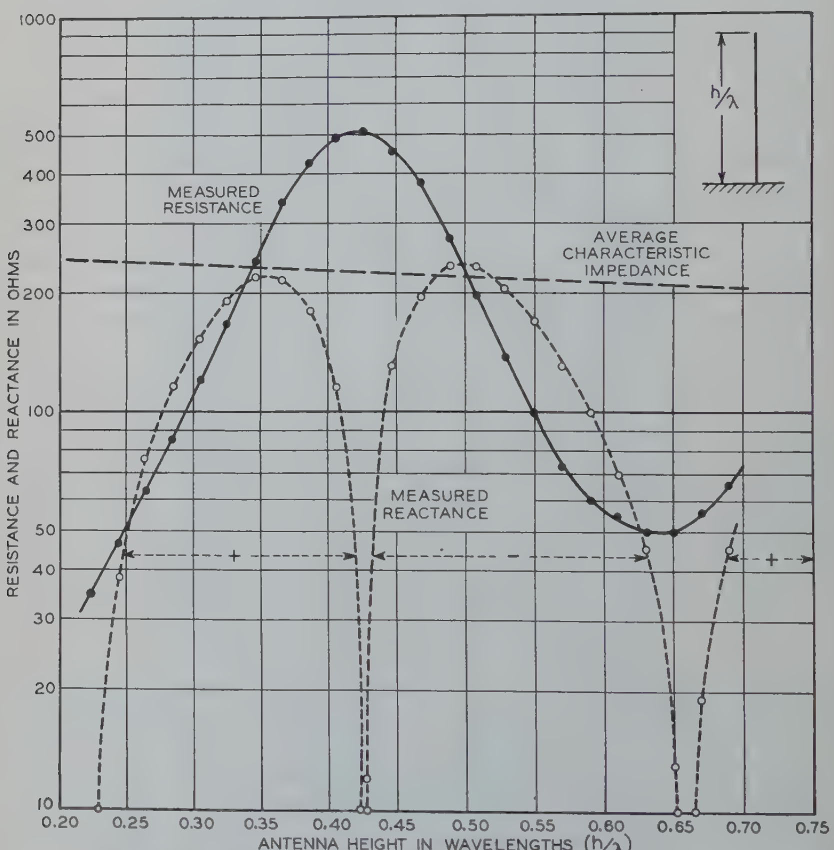

Fig. 4—Resistance, reactance, and characteristic impedance of the WWJ uniform cross-section vertical radiator.

It appeared that the impedance measurements at the antenna base were including the effects of a series inductance not considered in these equations as the locus of the measured impedance vectors is raised vertically from the computed curve. It was also found that the measured impedance vectors were rotated around on the locus curve

[1] E Siegel and J. Labus, "Impedance of antennas," *Hochfrequenz. und Elektroakustik*, vol. 43, pp. 166–172; May, (1934).

in a clockwise direction. This latter is the effect that would be produced if the antenna had a greater electrical length than the formulas would account for. However, measurements of the standing current wave on the antenna, which will be explained later, indicate that the physical height was about 95 per cent of the electrical length and this value is in close agreement with that predicted by the transmission line formulas.

Siegal and Labus have found excellent agreement between computed and experimental impedance data for horizontal antennas arranged so that the effect of the ground was largely eliminated. Since the data presented here were taken between an antenna base and ground it is probable that the ground influenced the data in a manner not taken into account by the formula. This is to be expected however, as in actual practice an impedance may be encountered by the ground currents in distributing through the ground network and the formulas for computing the radiation resistance are developed on the assumption of a perfectly conducting ground plane.

It may be significant that the differences between the computed and measured reactance when the antenna was operated at one-quarter and three-quarter wave length were respectively 25 and 75 ohms positive reactance. These differences correspond to the effect of an additional series inductance of 6.8 microhenrys. If in addition a lumped capacitance of about 200 micromicrofarads is also assumed to exist in shunt with the antenna base the computed values for the antenna impedance agree closely with the measured results over the band of frequencies studied. It is known that the base insulator contributed about 30 micromicrofarads to this apparent shunt capacitance.

Impedance of the Shunt-Excited Antenna

The shunt-excited antenna may be analyzed into the following components: (A) The vertical portion above the tap point of the inclined conductor and (B) the vertical portion below the tap point. The impedances of these two portions with respect to ground are in parallel and form the terminating impedance for a third component comprising the inclined conductor. A calculation of the impedances at the base of the inclined conductor using this concept of circuit mechanics has been found to agree to a good approximation with the measured values.

To arrive at quantitative values for the impedance of the antenna above the tap point of the inclined conductor, the same locus of the impedance measurements which were made at the base of the insulated antenna was assumed to apply to the section above the tap. The frequency at which any one impedance at the base was measured was

modified by the ratio of the total height of the structure to the height of the section above the tap point, thereby obtaining a new frequency at which approximately the same antenna impedance might be expected to exist at the tap point. Thus the plot of impedances at the base of the structure as a function of frequency is shifted along the frequency axis to obtain the impedance data for the antenna above the tap point.

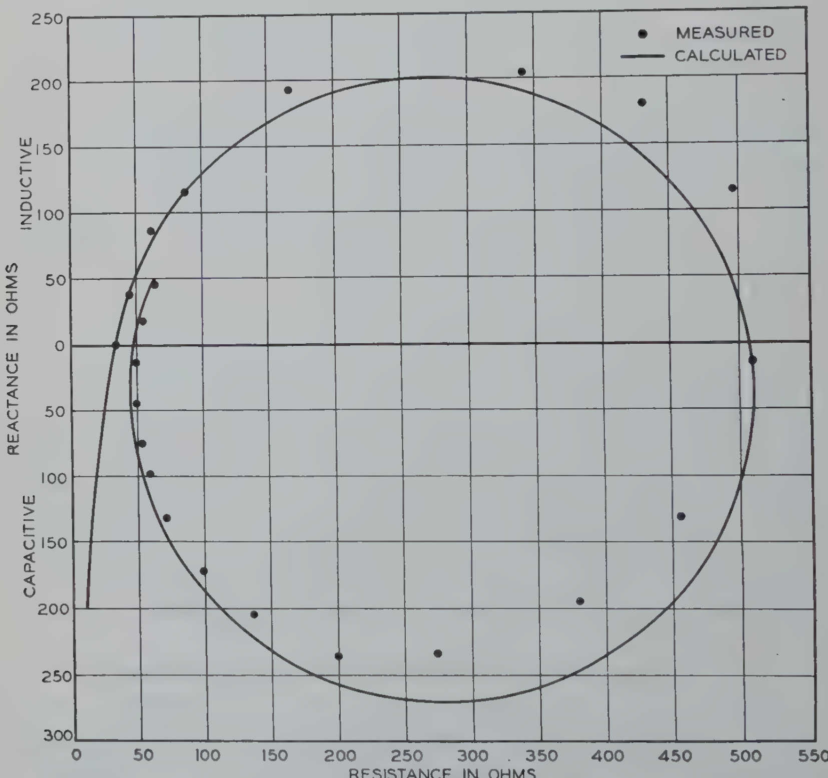

Fig. 5—Locus of impedance vectors at the base of the WWJ uniform cross-section vertical radiator.

The impedance of that portion of the antenna between the tap point of the inclined conductor and ground was considered to be a pure reactance because of its short length. The reactance was computed from its physical dimensions based on the static formula for a straight conductor in free space. At the higher frequencies where the length of this section becomes a larger fraction of a wave length it was realized that the reactance would depart somewhat from a linear relationship with frequency. Based on transmission-line theory, this departure from

linearity with frequency would be proportional to the tangent of the electrical length. This correction, although taken into account, was small even at the highest frequencies considered. It was found also that effectively an additional inductance could be considered in series with the computed reactance of the structure between the tap point of the inclined conductor and ground. When this inductive reactance or its equivalent effect is included in the calculations for the impedance at the base of the inclined conductor close agreement is obtained with the measurements. It is interesting that its value (which in this case was 6.8 millihenrys) was found to be the same as the value observed in the case of the insulated antenna when it was operated at one-quarter and three-quarter wave lengths.

If the inclined conductor is considered as a single wire transmission line its input impedance is a function of its resistance, characteristic impedance, electrical length, and terminating impedance. Its terminating impedance is considered to be the resultant value of the antenna impedance above the tap in shunt with the total reactance below the tap point. The correlation of calculated impedance at the base of the coupling line with the measured data is shown on Fig. 6. The discrepancy between the calculated curve and measured points may be partly due to coupling effects between the antenna and coupling line which were not considered.

The impedance at the base of the inclined conductor may be adjusted to the desired impedance by two methods:

1. The distance between the base of the antenna structure and transmission line termination may be varied. This adjustment changes the length, but does not noticeably influence the terminating impedance of the inclined conductor.

2. The height of the vertical coupling section may be varied. This adjustment changes all parameters but has the greatest influence upon the terminating impedance of the inclined conductor. It will be seen from (B) in Appendix II that the changes are to a certain extent compensating. Consequently, the adjustment is not critical and the desired impedance can be obtained within very close limits.

It is suggested that in practice the distance between the antenna base and the transmission line be fixed and adjustments made according to method No. 2. This suggestion is made merely in the interests of simplicity of design practice, where it is desirable to predetermine the physical location of the concentric transmission line termination. The data on Fig. 6 were taken using a No. 8 B & S gauge copper wire as the inclined conductor. In practice it is expected that a larger conductor

will be used with correspondingly lower characteristic impedance. This would have the desirable effect of increasing the resistance to reactance ratio at the base of the inclined conductor.

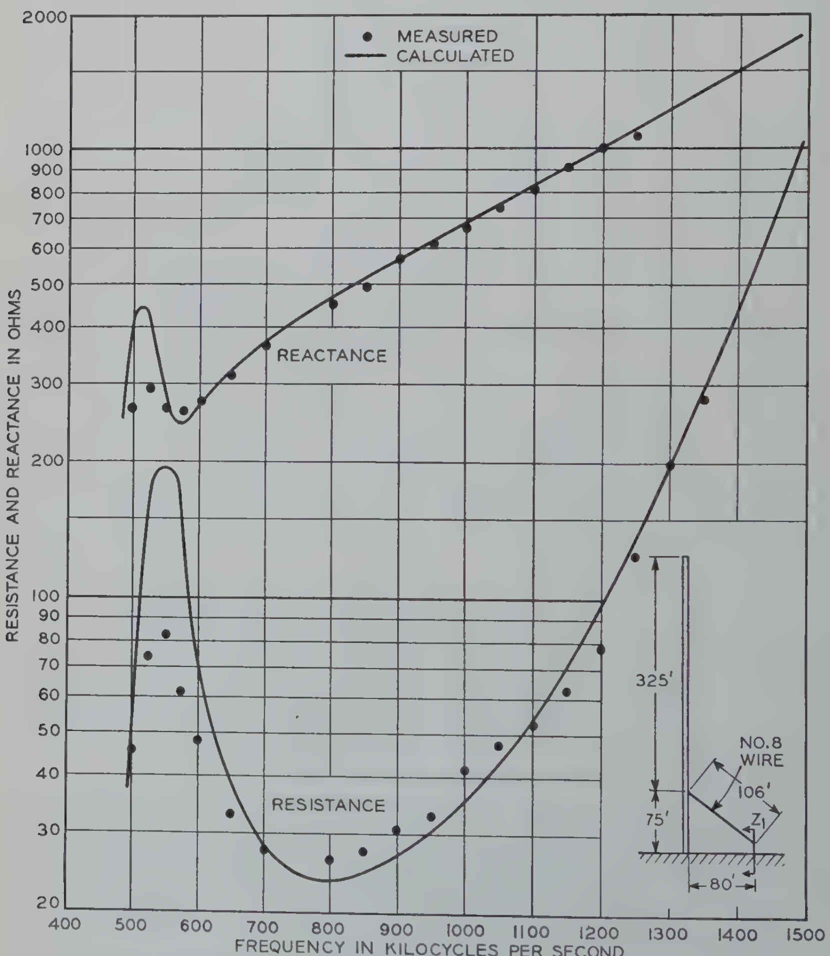

Fig. 6—Resistance and reactance of the shunt-excited antenna.

Current Distribution

To simplify the mathematics in the computation of antenna performance, it has been customary to assume that the current is sinusoidally distributed along the radiating element. In a uniform transmission line which possesses no losses in the form of radiation or otherwise, this assumption is strictly true. However, in the actual antenna the

constants are not uniformly distributed, and power losses occur mainly in the form of radiation. As a result, the current distribution must depart from the sinusoidal form. Furthermore, the phase of the current at various points within each half cycle of the standing wave also departs from that implied by the sinusoidal assumption.

The reason for this departure[2] becomes apparent if we consider the current at any point to be the resultant of two vectors rotating in opposite directions at the same rate. One vector represents the current traveling away from the generator to the far end of the antenna and the other represents the current reflected back from the far end of the antenna toward the generator with a smaller amplitude due to radiation losses. From such an illustration it may be seen that the resultant vector is at no time equal to zero amplitude and its phase is continually changing as the components rotate. If no losses were present, each vector would have the same amplitude and the resultant vector would then vary sinusoidally as the components rotated. From this reasoning it follows that an antenna, which is intended to radiate power, will not have a sinusoidal current distribution. Actually it may depart materially from that form even though the cross-sectional dimensions of the structure are made uniform.

P. O. Pedersen[3] has extensively investigated this departure from sinusoidal form in small diameter antennas constructed of wire and has concluded that while the departure is appreciable, the radiation characteristics, computed from actual current distribution, agree very well with those predicted using the sinusoidal assumption. This agreement may not be as good in the case of tower radiators which have a much larger diameter, but experience has indicated that the assumption usually leads to sufficient accuracy for practical estimates. The rigid support at the base of the shunt-excited antenna permits the use of smaller cross-sectional dimensions in the case of self-supporting structures.

Measurement of the Current Distribution

The current distribution which is sometimes referred to as the standing wave on a radiating element can be measured with an acceptable degree of accuracy if some important precautions are taken in the collection of data. The measurements are usually made by placing an exploring loop circuit, which contains a current indicating device, in proximity to the antenna progressively at many points

[2] There is not at present any rigorous solution.

[3] "Radiation from a vertical antenna over flat perfectly conducting earth," *Danmarks Naturvidenskabelige Samfund*, on Commission by G. E. C. Gad, Vimmelskaftet 32, Copenhagen, 1935.

throughout its length and plotting the data thus collected as an index of the current distribution along the antenna.

Since the exploring loop circuit current is taken as an index of the current at each point of observation, particular precautions should be taken to minimize the influence of the field emanating from other points along the conductor.

The antenna may be viewed as many elementary current elements each contributing a field intensity at the point where the exploring loop is located. The total field is the sum of these effects properly added in magnitude and phase. The field intensity from one of these elements is proportional to the amplitude of the current in the element and varies inversely as the square of the distance between the element and the exploring loop. It is also proportional to the sine of the angle between a line drawn from the element to the exploring loop and the center line of the antenna. Thus, if the exploring loop is close to the antenna the effects of current elements other than those in the immediate vicinity of the exploring loop are greatly reduced and it may be said that the loop samples the average current along a length of the antenna which is comparable to the distance the loop is away from the antenna.

If the antenna is nonuniform in cross section the field which is picked up at each sampling point when the loop is held close to the antenna is affected by the varying distances and angles to the current elements due to the antenna configuration and is likely to give erroneous results. In those cases where owing to the configuration of the tower it is necessary to hold the loop well away from the antenna, more careful consideration must be given to interpreting the results.[4]

The uniform cross-section design of the radiator at station WWJ presented, for the first time since the advent of tower radiators, an excellent opportunity to measure the distribution of current on a full size radiator without the afore-mentioned difficulties occasioned by nonuniformity of tower diameter. The exploring loop circuit used for collecting the data shown on Figs. 7 and 8 consisted of a small variable air condenser, vacuum tube rectifier, multiscale microammeter and a loop antenna from a Western Electric 44A field intensity measuring set. This latter was chosen for its rigid mechanical construction and the wooden housing of the loop served as a jig for obtaining a constant separation from the tower structure. The relative size of this loop with respect to the tower height was sufficiently small to give reasonably accurate samples of the current at the points under consideration.

[4] H. E. Gihring and G. H. Brown, "Tower antennas for broadcast use," Proc. I.R.E., vol. 23, pp. 311–358; April, (1935).

At the same time it was large enough to permit sufficient pickup of the field from the small currents provided by a low power oscillator. A rope suspension was arranged for carrying the apparatus up and down

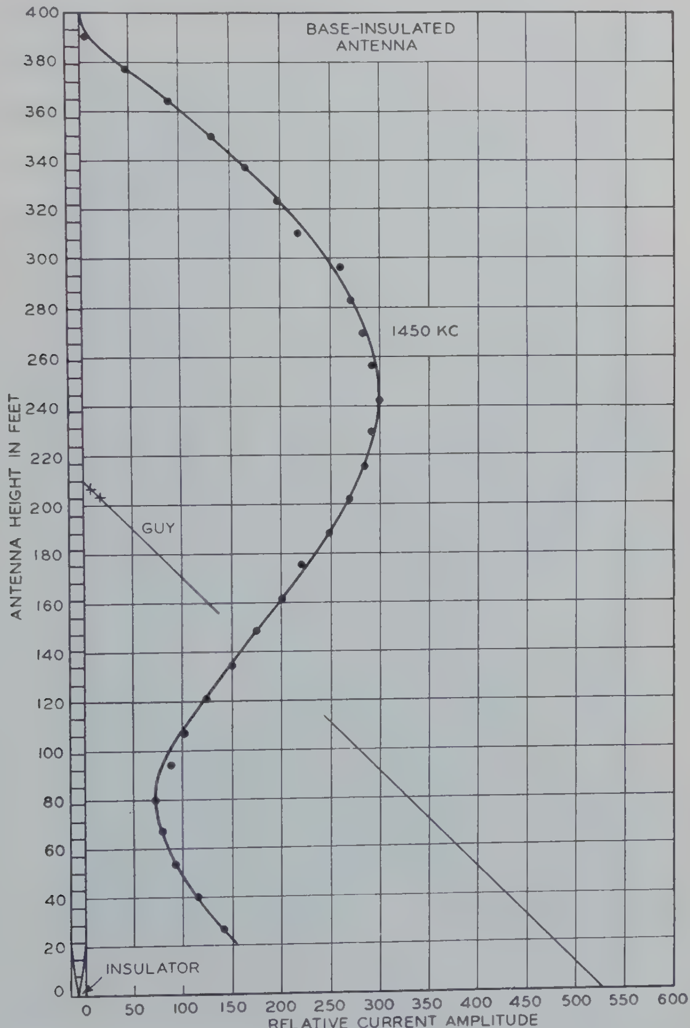

Fig. 7—Current distribution of the WWJ uniform cross-section vertical radiator.

the tower and also served as a support for the apparatus at the measuring points. When making measurements the loop was oriented to cut the magnetic field at right angles by supporting it firmly against one corner of the tower. In addition it was located at the same point

with respect to the tower cross members of each section, where a measurement was made. A photograph of the test apparatus is shown in Fig. 9.

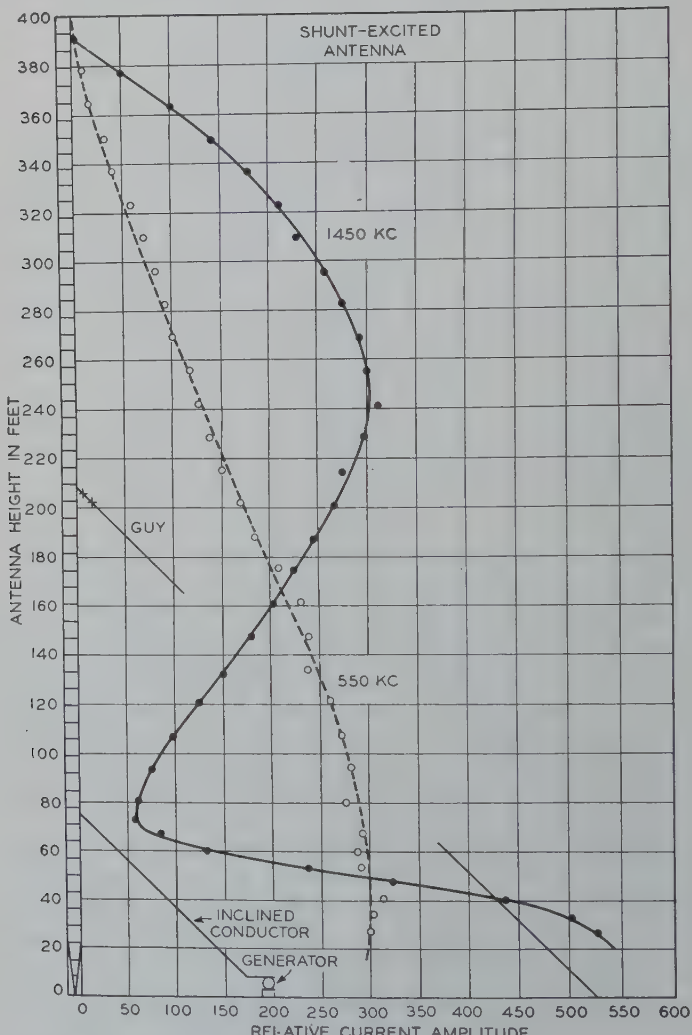

Fig. 8—Current distribution on the shunt-excited antenna.

Fig. 7 shows the current distribution measured by this method when the tower was insulated at its base and excited at a frequency of 1450 kilocycles. 1450 kilocycles is the frequency at which maximum ground plane field intensity was observed and also corresponds to a

standing wave length of about 0.64 wave length. By observing the standing wave at 1450 kilocycles it will be noted that the length of the wave between the two minimum points (top of the antenna and 80 feet above ground) is 320 feet. Since one half of the wave length in free space at 1450 kilocycles is 339 feet, the ratio of 320 to 339 indicated

Fig. 9—The apparatus used for measuring the current distribution.

that the apparent wave velocity on the radiator was about 95 per cent of the free space value.

Fig. 8 is a plot of similar data taken when the antenna was shunt excited. The 550-and 1450-kilocycle frequencies correspond closely to the 0.25- and 0.64-wave length mode of operation. When making the measurements below the tap point of the inclined conductor, the ex-

ploring loop was placed so that little, if any, field was picked up from the inclined conductor. Therefore, these data represent only the current relations in the vertical portion of the radiator. It will be noted from the 1450-kilocycle curve that the distribution is substantially the same as in the case of the insulated antenna except in the region

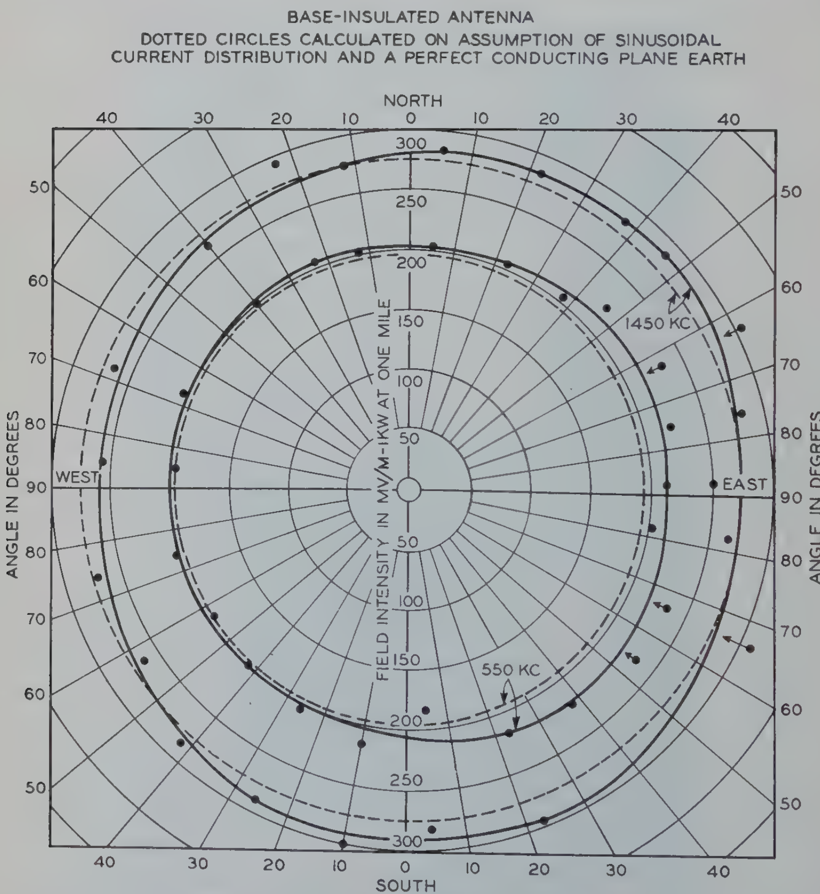

Fig. 10—Unattenuated field intensity distribution about the WWJ antenna (series excited)

below the tap point where the current builds up to much larger values. This is to be expected as the voltage with respect to ground must go to zero at the base.

While in this case, the current amplitude in the vertical section below the tap is larger than in the case of the insulated antenna it was believed that the phase relations between the current in that section

and the current in the inclined conductor would produce a canceling effect upon the radiated field. To determine more definitely the effects of the exciting circuit upon the radiated field, comparative field intensity measurements between the insulated and shunt-excited antenna were made.

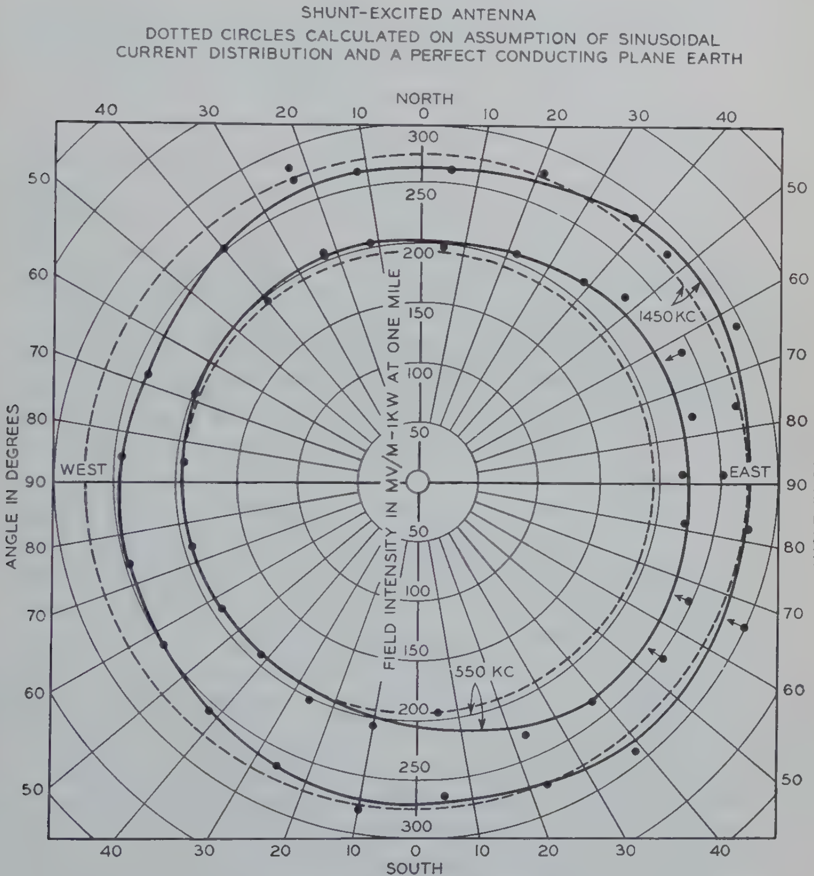

Fig. 11—Unattenuated field intensity distribution about the WWJ antenna (shunt excited).

Field Intensity Measurements and Data

The ground plane field intensity was investigated with a Western Electric 44A field intensity measuring set. A low power oscillator was used to excite the antenna but for comparison purposes the measured data were corrected to correspond to a power level of 1000 watts and a constant distance of one mile from the antenna. The

results at frequencies which corresponded to an antenna height of about 0.25 and 0.64 wave length are shown in polar form on Figs. 10 and 11. It will be seen from these data that the field intensity distribution patterns for the base insulated and shunt-excited antenna are substantially the same.

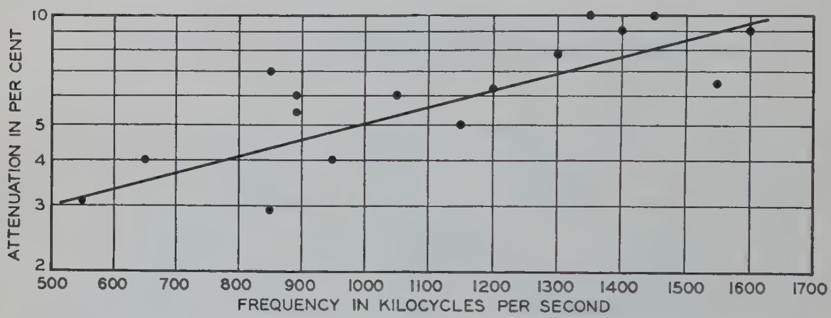

Fig. 12—Average attenuation in the first mile from the WWJ antenna.

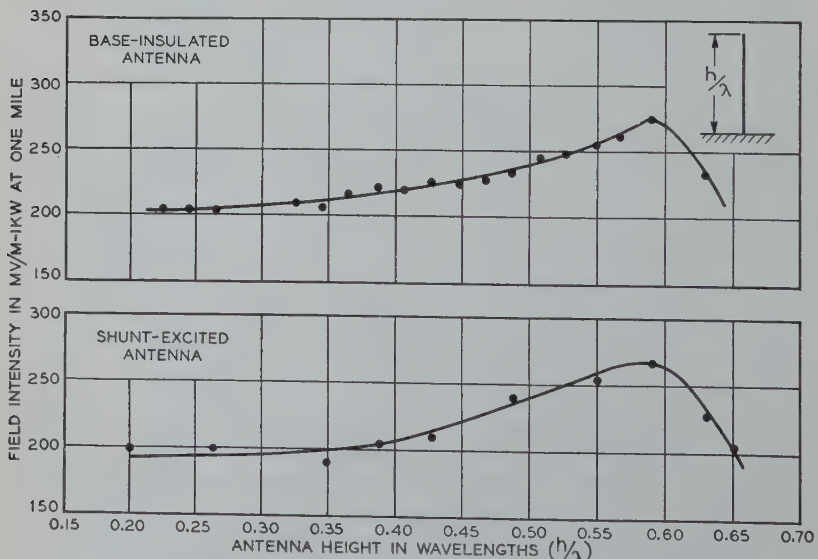

Fig. 13—Measured field intensity from the WWJ antenna as a function of the antenna height in wave lengths.

Attenuation of the field about the WWJ site was comparatively low but as might be expected this attenuation increased at the higher frequencies. The measured attenuation in many directions about the antenna within the frequency band of interest is shown on Fig. 12. The data are somewhat dispersed due largely to the variation in attenuation with direction from the antenna.

The measured field intensity corrected for 1000 watts was plotted as a function of the physical height of the radiator in wave lengths for both methods of excitation and is shown in Fig. 13. It will be noted that in the region of 0.35 wave length physical height the measured field was slightly less in the case of the shunt-excited antenna. It was found that this slight departure was caused by losses in the ground system near the base of the antenna, which can be overcome by the use of an improved ground system.

In the case of either the series or shunt-excited antenna there appears to be little economical justification for antenna heights between 0.25 and 0.5 wave lengths on the basis of increased signal strength. Theoretical conclusions and measured results show that the field intensity curve rises very slowly for antenna heights between 0.25 and 0.4 wave length. For example only 12 per cent or one decibel improvement in field intensity can be expected under the best of conditions, when the antenna height is increased from 0.25 to 0.4 wave length. This fundamental fact makes it difficult to justify the intermediate heights as 5 to 10 per cent is considered good accuracy in the measurement of field intensities. On the other hand 32 per cent or 2.4 decibels improvement can be expected if the antenna height is increased from 0.25 to 0.55 wave length and what is probably more important in the case of high power stations a substantial increase in the fading free area is realized.

Through the courtesy of the National Life and Accident Insurance Company, field intensity tests were made at distances ranging from 35 to 110 miles in several directions from the 0.58-wave length vertical radiator at station WSM Nashville, Tenn. Automatic recording equipment was used for the collection of these data. The antenna was excited by the shunt and series method alternately every hour between midnight and 8 A.M. over a period of three weeks. An examination of these data showed that there was no discernible difference in the fading characteristics between the two methods of excitation. A reproduction of a typical record taken at a distance of 74 miles from the antenna is shown in Fig. 14.

ACKNOWLEDGMENT

The authors wish to acknowledge the co-operation of the management and technical staffs of Radio Stations WWJ, Detroit, Michigan, and WSM, Nashville, Tennessee, in the collection of data given in this paper.

APPENDIX I

In computing the resistance R and reactance X at the base of the insulated antenna, the antenna was considered as an open-cir-

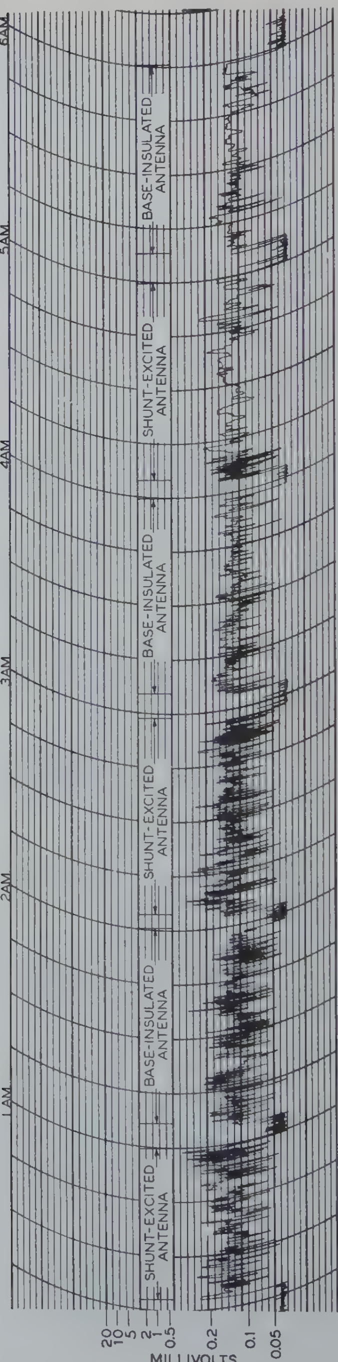

Fig. 14—Automatically recorded field intensities from the 0.58-wave length vertical radiator at station WSM (series and shunt excited).

cuited radio-frequency transmission line. The results of the method of investigating the flow of energy near the antenna were used for determining the average characteristic impedance and attenuation.

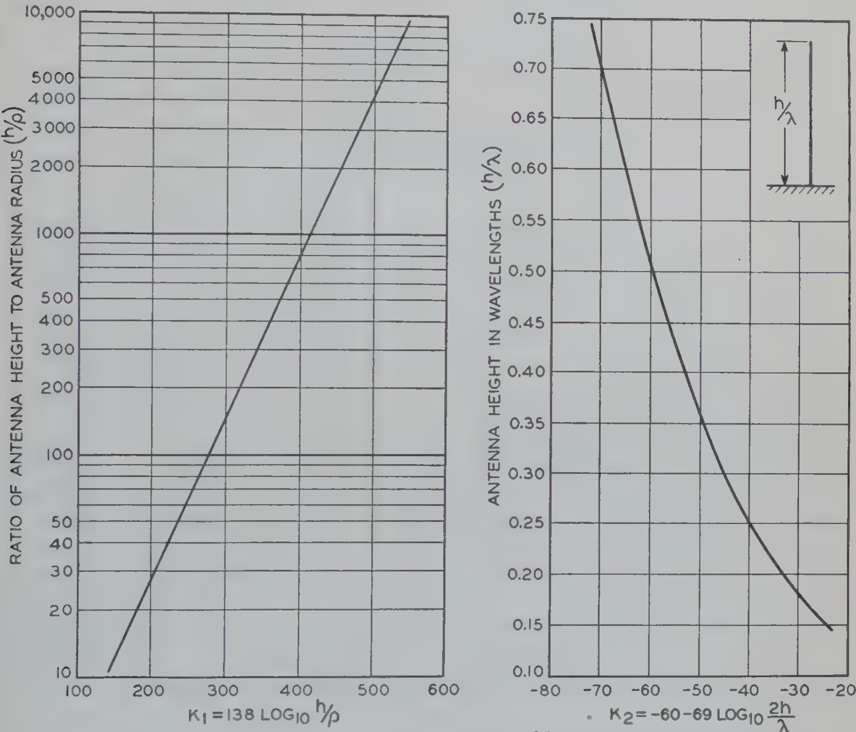

Fig. 15—Characteristic impedance of vertical antennas $Z_0=K_1+K_2$.

The characteristic impedance Z_0 was found to be a function of the physical dimensions of the antenna and was computed from the following:

$$Z_0 = K_1 + K_2 \qquad \text{(see Fig. 15)}, \tag{A}$$

where

$$K_1 = 138 \log_{10} \frac{h}{\rho}$$

and,

$$K_2 = -\left(60 + 69 \log_{10} \frac{2h}{\lambda}\right),$$

h = antenna height above ground,

ρ = radius of the antenna conductor,

λ = the wave length in free space.

A value obtained for an equivalent uniformly distributed resistance of the antenna was derived from the radiation resistance. The radiation resistance may be expressed by the following which holds for antennas longer than 0.2 wave length:

$$R_s \cong 15\left[-\frac{\pi}{2}\sin 4\pi\frac{h}{\lambda}+\left(2.303\log_{10}\frac{2h}{\lambda}+1.722\right)\cos 4\pi\frac{h}{\lambda} + 2\left(2.415+2.303\log_{10}\frac{2h}{\lambda}\right)\right] \quad \text{(see Fig. 16).} \qquad \text{(B)}$$

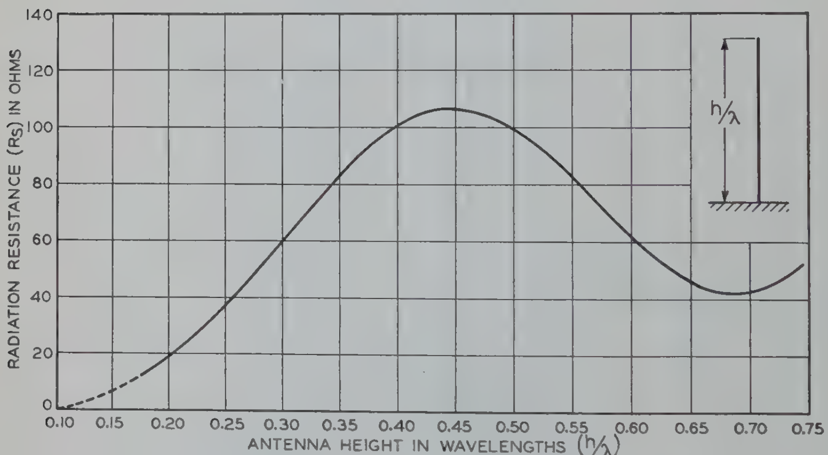

Fig. 16—Radiation resistance (R_s) of vertical antennas.

The equivalent resistance is

$$rl = \frac{4R_s}{1-\dfrac{\sin\dfrac{4\pi h}{\lambda}}{\dfrac{4\pi h}{\lambda}}} \qquad \text{(see Fig. 17),} \qquad \text{(C)}$$

where,

$$l = 2h.$$

The attenuation constant

$$\alpha l = \frac{rl}{2Z_0}. \qquad \text{(D)}$$

Finally having found Z_0 and αl we may obtain R and X by the following transmission line equations:

$$R = Z_0 \frac{\sinh \alpha l - \dfrac{\alpha l}{4\pi \dfrac{h}{\lambda}} \sin 4\pi \dfrac{h}{\lambda}}{\cosh \alpha l - \cos 4\pi \dfrac{h}{\lambda}} \tag{E}$$

and,

$$X = Z_0 \frac{\sin \dfrac{4\pi h}{\lambda} + \dfrac{\alpha l}{4\pi \dfrac{h}{\lambda}} \sinh \alpha l}{\cosh \alpha l - \cos 4\pi \dfrac{h}{\lambda}}. \tag{F}$$

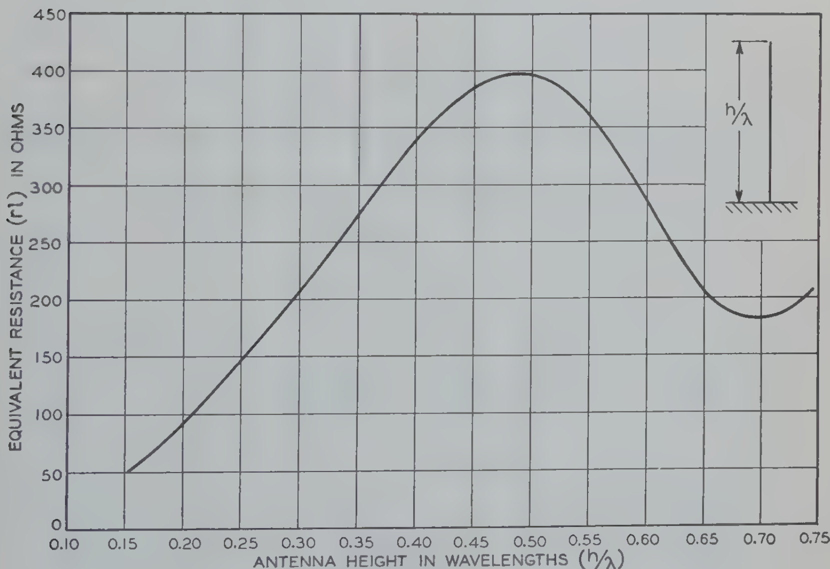

Fig. 17—Equivalent resistance (rl) of vertical antennas.

An approximate formula for the average velocity of propagation along the antenna

$$v \cong c\left(1 - \frac{2680}{Z_{0\frac{1}{4}}{}^2}\right), \tag{G}$$

where

c is the velocity in free space,

$Z_{0\frac{1}{4}}$ is the average characteristic impedance at the one-quarter wave length height.

Appendix II

Impedance of the Shunt-Excited Antenna

Based upon the assumptions made in the body of the paper the terminating impedance of the inclined conductor

$$Z_r = \frac{Z_a(Z_s + Z_g)}{Z_a + Z_s + Z_g}, \tag{A}$$

where,

Z_a = the antenna impedance above the tap position,
Z_s = the impedance of the antenna structure below the tap position,
Z_g = a correction factor explained in the text.

The sending end impedance of the inclined conductor is then by transmission line theory for a lossless line

$$Z_s = \frac{Z_0 Z_r(1 + \tan^2 \beta)}{Z_0^2 + Z_r^2 \tan^2 \beta} + j\frac{\tan \beta(Z_0^2 - Z_r^2)}{Z_0^2 + Z_r^2 \tan^2 \beta}, \tag{B}$$

where $\beta = 2\pi$ times the length of the inclined conductor in wave lengths radians.

The characteristic impedance of the inclined conductor

$$Z_0 \cong 138 \log_{10} \frac{4D}{d}, \tag{C}$$

where,

D = the average height of the inclined conductor above ground,
d = the diameter of the inclined conductor.

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TELEVISION IN GREAT BRITAIN*

By
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Summary—*The development of television in Great Britain is treated in this paper and a short historical background is given, tracing the development of television in Great Britain from 1929, when the British Broadcasting Corporation first gave the Baird Television Company facilities for experimental transmissions of low definition television from an ordinary broadcast station. In May, 1934, the Postmaster-General appointed a Committee to consider the development of television, and to report on the conditions under which any public service of television should be provided. The Committee recommended in 1935 that no low definition television service should be adopted for a regular public service, and was of the opinion that high definition television had reached such a standard as to justify the first steps being taken towards the early establishment of a public television service of this type. The British Broadcasting Corporation was entrusted with the development of this service. The paper then gives a brief technical description of the London television station, which is the practical effect the British Broadcasting Corporation has given to the Television Committee's recommendations. The station has been built at Alexandra Palace, some six miles north of the center of London. Two complete television systems were installed, one by Baird Television, Limited, and the other by the Marconi-E.M.I. Television Company, Limited. Each consists of studio and control room equipment and a vision transmitter. A third transmitter common to both systems provides the sound program. An aerial mast carries two separate aerials, one for transmitting the vision and the other for transmitting the sound. The vision aerial is common to both systems. Vision is radiated on a frequency of 45 megacycles, while sound is radiated on a frequency of 41.5 megacycles. The Baird system uses 240 lines sequential scanning, 25 frames per second, while the Marconi-E.M.I. system uses 405 lines interlaced, at 50 frames per second, each of $202\frac{1}{2}$ lines. The Television Advisory Committee, before approving different standards of frame frequency and definition for the two systems, was satisfied that receivers could be constructed capable of receiving both types of transmission without undue expense or complicated adjustment. The commercial receivers now on the market accomplish this by a single switch.*

On November 2, 1936, a regular television service for reception by the public was opened by the Postmaster-General, regular programs being given twice a day from 3:00 to 4:00 P.M. and 9:00 to 10:00 P.M., except on Sundays.

AS FAR back as the autumn of 1929, the British Broadcasting Corporation gave the Baird Television Company facilities for experimental low definition transmissions of television from an ordinary broadcast station. During the next two or three years a large number of experimental transmissions were carried out by the Baird Company independently, as well as in conjunction with the British Broadcasting Corporation.

* Decimal classification: R583. Original manuscript received by the Institute, November 12, 1936. Presented before New York Meeting, November 12, 1936.

Fig. 1—Alexandra Palace, London Television Station, Baird studio, showing intermediate film scanner.

In August, 1932, the British Broadcasting Corporation inaugurated a regular service of low definition television on medium wave lengths, transmitting two or three times a week. The Baird system was used, the number of lines was 30 and the number of pictures per second $12\frac{1}{2}$. The service was experimental and it was terminated on September 15, 1935.

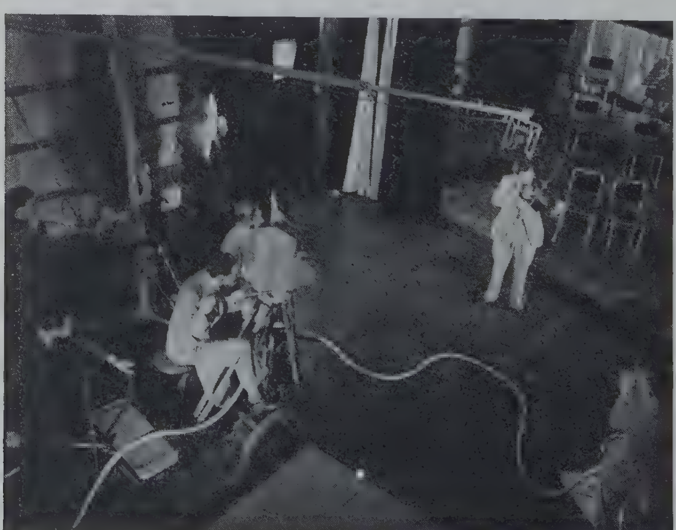

Fig. 2—Alexandra Palace, London Television Station. The Marconi-E.M.I. studio showing two Emitron instantaneous television camers in use one transmitting the program; the other ready to be "faded-in" for a different "shot."

In May, 1934, the Postmaster-General appointed a Committee with the following terms of reference: "To consider the development of television and to advise the Postmaster-General on the relative merits of the several systems and on the conditions under which any public service of television should be provided." Both the Post Office and the British Broadcasting Corporation were represented on this Committee. Its report was presented in January, 1935.

Fig. 3—Alexandra Palace, London Television Station. The mast and transmitting aerials (vision above) (sound below).

The Committee recommended that no low definition television service should be adopted for a regular public service, and it was of the opinion that high definition television had reached such a standard as to justify the first steps being taken towards the early establishment of a public television service of this type. The Committee recommended that the definition should not be less than that given by 240 lines per picture with a minimum picture frequency of 25 pictures per second. It also recommended that, in view of the close relationship between sound and television broadcasting, the British Broadcasting Corporation should be entrusted with the television service.

While the British Broadcasting Corporation should exercise control of the operation of the television service, it was recommended that the initiation and early development of this service should be planned and

guided by an Advisory Committee appointed by the Postmaster-General, on which the Post Office, the Department of Scientific and Industrial Research, and the British Broadcasting Corporation should be represented.

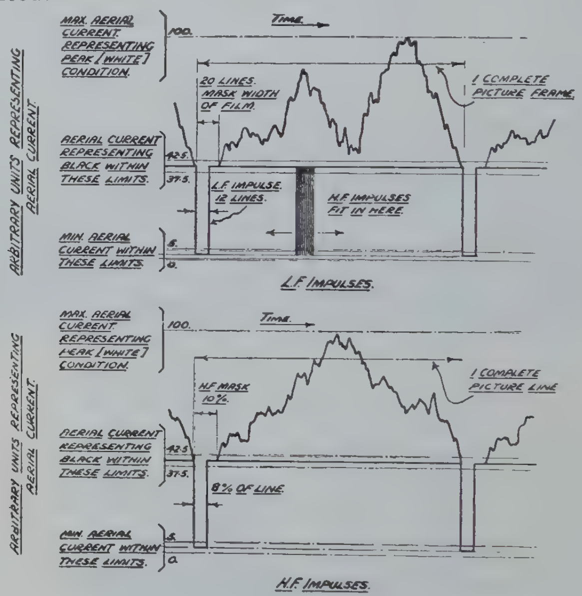

Fig. 4—Baird system. Characteristics of vision signal.

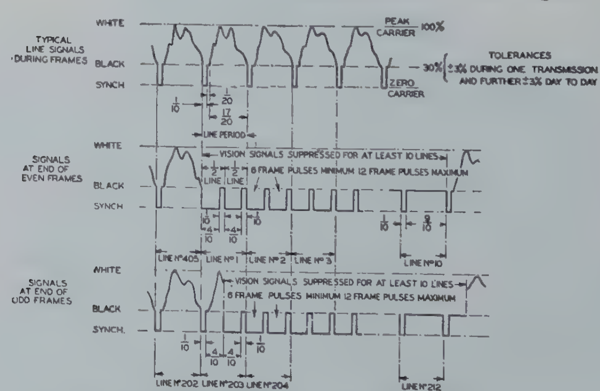

Fig. 5—Marconi-E.M.I. system. Characteristics of vision signal.

The Committee also recommended that a start should be made by the establishment of a service in the London area and that two systems, that of Baird Television, Limited and that of the Marconi-E.M.I. Television Company, Limited, should be used under conditions which admitted of a comparison being made of their respective merits.

The following is a very brief technical description of the London television station, which is the practical effect the British Broadcasting Corporation has given to the Television Committee's recommendations. Alexandra Palace is a large building situated on a hill, 300 feet above sea level and some six miles north of central London. It has been a North London landmark and a center for exhibitions and amusements for about sixty years. The British Broadcasting Corporation has leased from the Alexandra Palace trustees 31,840 square feet of floor space at the southeast corner of the building, comprising three large halls on the ground floor, the rooms over them on the first floor and the south-

Fig. 6—Baird teleciné scanners. Monitoring and control racks in background.

east tower. A further area of 24,525 square feet, comprising the theater and associated rooms, is also available.

On the ground floor there are the transmitter rooms, a film-viewing room, a restaurant, and a kitchen, while the rooms above have been treated to form two large studios with control rooms and apparatus rooms separating them. Dressing rooms and make-up rooms for band and artists have been constructed, separated from the studios by a corridor. Office accomodation has been provided in the tower at the southeast corner. This tower also carries the mast and aerial system.

The two main studios, one for use with each of the television systems, are 70 feet by 30 feet by 25 feet high. Acoustically, the studios are considerably more "dead" than is the general practice for sound broadcasting in Great Britain. The walls are covered entirely, except for door and window openings, with sheets of asbestos compound which has a high degree of sound absorption. As this material has a rather rough surface, it is covered up to about ten feet from the floor with a protective fabric which does not affect the sound-absorbing properties

of the compound. The ceilings of the studios are treated with building board, as commonly used in ordinary broadcast studios. The floors are covered with black linoleum over which can be laid any type of flooring which may be required.

Several microphone points are installed in each studio, and they are arranged to allow the use of any type of microphone which may be required. Portable stands of the "lazy-arm" type are also provided.

Each studio is fitted with two stages equipped with curtains, the detailed arrangements of the stages and curtains being different in the

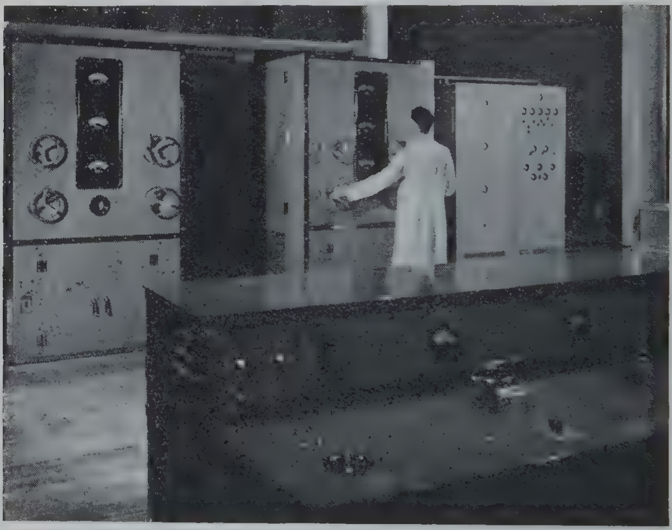

Fig. 7—Alexandra Palace, London Television Station. Baird television radio transmitter. Control desk, foreground. Crystal drive, right background. Intermediate-radio-frequency amplifier, center background. Power output stage, left background.

two studios, to take account of the different requirements of the two systems. A number of overhead battens, each of which carries several lighting circuits, has been provided in each studio. There is also a large number of wall sockets for portable lighting. In each studio a large lighting switchboard has been installed, with provision for the separate control, dimming, etc., of every circuit. In addition, there are arrangements for preselective switching and bank-dimming of any number of circuits, and the whole equipment has been designed to give the maximum possible flexibility. In addition to the above, a lighting bridge has been erected across the Marconi-E.M.I. studio to give further lighting facilities. All the lighting in both studios (a maxi-

mum of 50 kilowatts each) is at present of the incandescent lamp type, using spot- and floodlighting, on similar lines to that employed in theaters and film studios, but modifications are contemplated with developments in television technique.

Ventilation has been provided in the studios by means of extract fans situated in enclosures formed on the adjoining colonnade. Full air conditioning has not been attempted, since the studios are not regarded as permanent, but the ventilation is sufficient to keep the studios at a moderate temperature when full lighting is used, and to allow the temperature to be adjusted within normal limits.

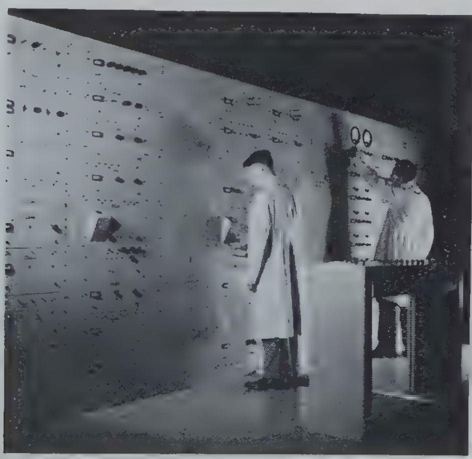

Fig. 8—Alexandra Palace, London Television Station. Marconi-E.M.I. system, control room. Emitron camer amplifiers (right), synchronizing oscillators (left).

The southeast tower was converted to provide offices for the television staff, and the existing ornamental pylon was removed and replaced with a steel mast to carry the vision and sound aerials. The top of the mast is 300 feet above the ground, the height of the steelwork above the brick tower being 215 feet. The height of the vision aerial above sea level is thus approximately 600 feet.

Two separate aerial systems are carried by the tower, one for vision and one for sound. Both systems are similar, each consisting of a number of vertical aerial elements arranged round the mast, those for vision being above and those for sound beneath. Each aerial consists of eight push-pull end-fed vertical dipoles spaced at equal angles round the mast, together with a similar set of dipoles used as reflectors to avoid induced currents in the mast structure and to increase the radiated field. The aerials are connected to junction boxes, with which

are associated a number of impedance-matching transformers to correct the aerial response. The aerial systems are connected to the transmitters by means of two five-inch concentric feeders which pass down the mast and along to the transmitting rooms, a change-over switch being provided so that either vision transmitter can be connected to the vision aerial.

The transmitter to radiate the sound accompanying the vision program is capable of operating over a band of frequencies from 35 to 50 megacycles, the working frequency being 41.5 megacycles, and the output power rating three kilowatts capable of 90 per cent peak modulation (Copenhagen rating). The frequency response of the transmitter is substantially flat between 30 and 10,000 cycles, the maximum departure being less than two decibels over this range, while the low-frequency harmonic content introduced by the transmitting apparatus is very low.

Of the two systems of television in operation, the Baird system is using 240 lines sequential scanning, 25 frames per second. Baird Television, Limited, has installed two complete telecinė scanners for film transmission and an intermediate film system in which the scene to be televised in the studio is photographed, developed, fixed and washed, all within forty seconds, the film then passing through what is, in effect, a telecinė scanner adapted to scan the film while it is wet. The sound is also recorded on the film in order that it may be synchronized with the vision. In addition, the Baird system uses mechanical spotlight scanning for direct television of head and shoulder subjects from a small studio. At the time of writing it is understood that the Baird Company is experimenting with an electron camera of the Farnsworth type.

The Marconi-E.M.I. system uses the Emitron instantaneous television camera, with electrical scanning, for studio and outside direct television as well as for film scanning. The picture is scanned with 405 lines interlaced, at 50 frames per second, each of 202½ lines. All synchronizing impulse generators and vision and audio amplifiers are installed in a central control room, and provision is made for fading from the output of one group of cameras to another, six cameras in all being fitted.

Each system has its own vision transmitter working on a carrier frequency of 45 megacycles, the power of the transmitters in each case being 17 kilowatts peak, when giving peaks of maximum modulation which correspond in these systems to the transmission of full white. The characteristics of the radiated signals are shown in Figs. 4 and 5.

The Television Advisory Committee, before approving different

standards of frame frequency and definition for the two systems, was satisfied that receivers could be constructed capable of receiving both types of transmission without undue expense or complicated adjustment. The commercial receivers now on the market accomplish this by a single switch.

The first experimental transmissions from the London television station took place just before the opening of this year's London radio exhibition. During this exhibition, demonstrations of reception of pictures from Alexandra Palace were given, and more than 100,000 people saw them. The station was then closed down for a short time

Fig. 9—Alexandra Palace, London Television Station. Marconi-E.M.I. vision transmitter, modulator units. Foreground, control desk.

for adjustment, and from October 1 test transmissions were given twice daily for periods of an hour, chiefly to allow manufacturers to test out television receivers. These test transmissions concluded on October 31, and on November 2 a regular television service was opened by the Postmaster-General, the Chairman of the British Broadcasting Corporation, and Lord Selsdon, the chairman of the original television committee. Regular programs are being given twice a day, from 3:00 to 4:00 P.M. and from 9:00 to 10:00 P.M., except on Sundays.

Some seven or eight radio manufacturers have already put, or are putting, television receivers on the market, and indeed some receivers have already been sold to members of the public. One or two London stores have installed receivers on which their customers can see the transmissions, and one of the railway companies has installed a receiver in a waiting room at one of the London termini, admission being gained by the production of a railway ticket. Public demonstrations are also given at the Science Museum in South Kensington.

The present cost of a receiver is four or five hundred dollars and it is obvious that the audience for these transmissions is not likely to become very large until this price is considerably reduced. There is reason to hope that this will be done as public interest develops.

The programs are published weekly in advance in the London edition of the *Radio Times*, the British Broadcasting Corporation's program paper, as well as daily in the morning papers. To give some idea of our initial efforts, the following items are taken from the programs for the second week:

Nov. 9	O.B.	Demonstration of the new mobile post office.
	Studio	"Picture Page." A magazine program of items of general and topical interest.
Nov. 10	O.B.	Demonstration of horsemanship and jumping.
	O.B.	Demonstration of jumping Alsations.
	Studio	A star from the entertainment world.
	Studio	A specially arranged pageant of citizen soldiers of London who formed part of the Lord Mayor's Show the previous day.
Nov. 11	Studio	Special Armistice Day program.
	Studio	Ballet program.
Nov. 12	Studio	Extracts from the new opera "Mr. Pickwick," Albert Coates, the composer, conducting, about to be produced at Covent Garden.
	Studio	Ballroom dancing demonstration.
Nov. 13	Studio	Exhibits from the International Poultry, Pigeon, and Livestock Show.
Nov. 14	O.B.	A selection of cars taking part in the Veteran Cars' Parade the following day.
	Studio	Cabaret.

News reels and one or two short films also are shown.

Up to the present, we have not attempted any outside pickups further afield than those we have done in the grounds or inside the exhibition part of Alexandra Palace itself, a maximum distance between camera and control room of about 1000 feet.

A coaxial cable has been laid between Broadcasting House and Alexandra Palace, but the terminal gear has not yet been installed. This cable has been provided largely for test purposes, and, while it may be used occasionally for actual programs, there is no intention at present of providing extensive television studio accomodation in Broadcasting House.

In this paper there has been no attempt to make any critical study

of the television systems which we are using, or which we might have used, and it probably would be unwise to do so until we have obtained sufficient information based on practical daily use of the systems over a considerable period. Furthermore, in any comparison one should certainly take into account the results obtained from receivers in the hands of the general public. We are watching with great interest the reaction of the public, and further extensions of the service to other parts of the country will depend on the results of the experience we gain in London.

Author's Note:

Since this paper was read in New York on November 12, 1936, several months have elapsed, and on February 4, 1937, the Postmaster-General made the following announcement:

"The Postmaster-General announces that, as a result of the experience gained of television transmissions from the London television station at Alexandra Palace, the Television Advisory Committee have recommended that the London experimental period—during which different technical standards of transmission have been used during alternate weeks—should now be terminated, and that a single set of technical standards should be adopted for public transmissions from the London station. This recommendation, which has been approved by the Postmaster-General, provides for the adoption of standards as follows:

Number of lines per picture = 405, interlaced.
Number of frames per second = 50.
Ratio of synchronising impulse to picture = 30:70.

"These standards for the television service from the London station will not be substantially altered before the end of 1938. Consequent upon this decision, television transmissions from Alexandra Palace of 240 lines with 25 frames per second will be discontinued, and all future transmissions will be on the standards set out above, which will be known as the London Television Standards."

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RADIO INTERFERENCE FROM STREET RAILWAY SYSTEMS*

By
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THE conventional treatment of cases of industrial interference with radio reception is the application of one or another of various combinations of series low-pass and shunt high-pass filter elements connected in the supply lines as shown in Fig. 1. In the case of a defective high tension insulator or an arcing trolley wheel it is,

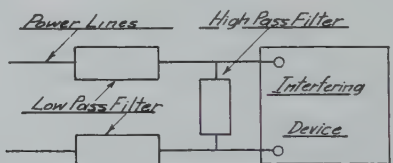

Fig. 1—Suppression of interference by filters.

however, obviously undesirable or even physically impossible, to add filter elements to the circuit.

A portable receiver equipped with either a directive or a probe antenna and aural, graphic, or oscillographic output indicating or measuring apparatus may be a valuable aid in tracing or studying a source of interference.[1] Such evidence may also be misleading because it simply indicates the direction or position of the maximum field, depending on the type of antenna in use. Very often the maximum field is not found at the source of the interference. As a case in point, a defective insulator on a transmission line has been observed to generate a noise level 75 per cent greater at a location twenty miles distant than the level in its immediate vicinity.

The investigation conducted by the writer followed along two lines. First, the streetcar itself and second, the overhead trolley system were examined.

The Streetcar

A number of streetcars of types in common use were submitted to measurement by applying a fixed potential at selected radio frequencies between the rail and the trolley wheel, the latter being re-

* Decimal classification: R430. Original manuscript received by the Institute March 31, 1936; revised manuscript received by the Institute, February 23, 1937.

[1] Merriman, "Radio Branch Bulletin No. 2," Ministry of Transport (Former Department of Marine), Ottawa, Ont., Canada.

moved from the trolley wire. Typical current readings taken with a thermal ammeter are shown graphically in Fig. 2. Strangely enough nearly all cars measured appeared as resonant circuits peaked broadly in the broadcast band with harmonics at even multiples.

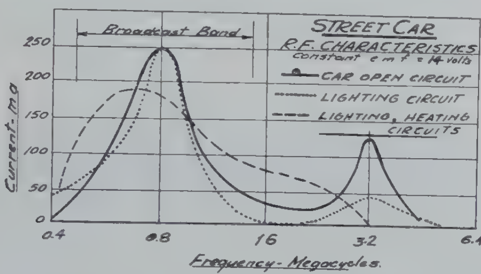

Fig. 2—Frequency characteristic of streetcar circuit prior to addition of filter.

Extending this measurement procedure by the usual substitution process,[2] further data, shown typically in Table I, were obtained. At

TABLE I
Typical Car Constants

Circuit	Direct-Current Resistance Ohms.	1000 kc Resistance Ohms	Natural Frequency Kilocycles	Inductance Microhenrys	Capacitance Microfarads
Open circuit	Infinite	44	1135	27	0.0013
Signal lamp only	1443	40	1135	27	0.0013
Signal and 30 lights	28	44	1140	28	0.0012
Signal, 30 lights, 15 heaters	10	60	1120	22	0.0023

radio frequencies it made only a very slight difference what circuits if any, were closed metallically.

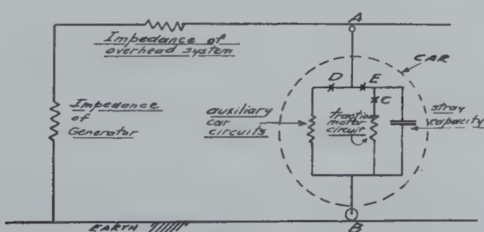

Fig. 3—Equivalent tramway circuit.

From such data it is evident that the car itself is free to respond to high-frequency potentials in exactly the same manner as a resonant circuit with distributed constants. Schematically the circuit is as

[2] Brown, "Radio Frequency Measurements."

shown in Fig. 3. This circuit is subject to interruption at A the trolley wheel, B the track, C the controller or controller relays, D the signal light, E the line breaker. It is obvious that a filter arrangement could be effective in localizing the trouble arising from certain of these circuit ruptures. A possible arrangement is shown in Fig. 4 where L is an inductance and C may be a condenser or the incidental capacitance of the installation.[1 3]

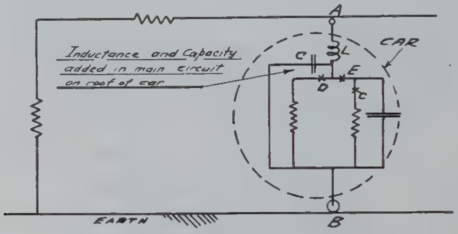

Fig. 4—Filter added to Fig. 3.

The action of the added coil is twofold. First, when the current in the circuit is changed by opening or closing of a branch the interfering high-frequency components of the resulting doorstep wave front are by-passed through the admittance of the condenser C and impeded from flowing out into the overhead trolley system by the inductance L. Second, the added inductance and capacitance alters the natural

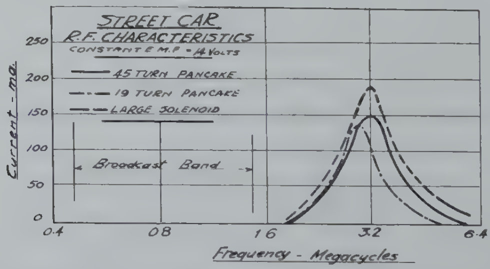

Fig. 5—Frequency characteristic of streetcar circuit after addition of filter.

frequency of the car, moving the points of resonance to some other part of the spectrum where interference is of less consequence. Such a condition is indicated in Fig. 5 as compared with Fig. 2.

The installation of such coils has proved advantageous in certain localities and of little use in others, which is precisely as one might expect. In cases where the interference results from circuits interrupted

[3] Peridier, "Electric Railway," *Bus and Tram Jour.*," 1934.

within the car, the filter localizes the trouble. In cases where the car wiring is actually radiating energy received from any circuit rupture, the added filter elements can be made to alter the frequency of the radiation to a less troublesome value. But no conceivable circuit element placed within the car circuit can have any effect whatsoever upon the wave that goes out along the overhead lines from a circuit rupture taking place at the trolley wheel. Since the natural frequency of the

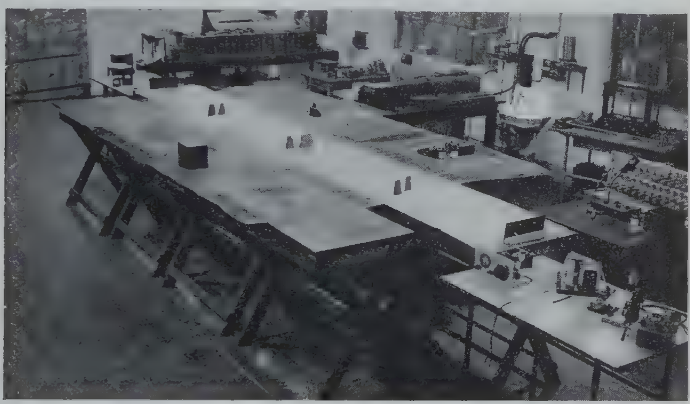

Fig. 6—Model trolley system used for study of electrical constants.

overhead system is constantly altering as the streetcar moves along it, such traveling waves are certain to have components of an interfering frequency when the car is travelling in particular districts.[4]

The Overhead Trolley System

The most powerful avenue of approach to a study of the overhead system is by means of a model.[5] Fig. 6 shows the arrangement employed by the writer. The physical and electrical ratio was 50 to 1. The lead-foil ground plane was extended laterally by metal gauze. The actual

TABLE II
Trolley System Electrical Constants

Type of System	Attenuation Constant	Characteristic Impedance Ohms	Natural Frequency Kilocycles
Single 2/0 trolley	4.64×10^{-6}	473	269
Single 4/0 trolley	2.38×10^{-6}	460	268
Double 4/0 with feeder, wood poles	1.42×10^{-6}	180	250
Double 4/0 with feeder, steel poles	1.48×10^{-6}	173	240

[4] Steinmetz, "Transient Electrical Phenomena and Oscillations."
[5] G. H. Brown and Ronald King, "High-frequency models in antenna investigations," Proc. I.R.E., vol. 22, pp. 457–480; April, (1934).

trolley wire is invisible in the picture but the metal poles on each side of the "street" can be seen. The constants measured on the model and checked by calculation are shown in Table II. These quantities are based on radio-frequency potentials and currents for a trolley length of 900 feet, the approximate distance between feeder points. The measurements include the effect of the capacitances of insulators and supports and neglect only the finite conductivity of the earth.

To investigate the interference from the model the arrangements shown in Fig. 7 were used. This diagram is a cross section of the model pictured in Fig. 6, with the ground plane and trolley wire perpendicular

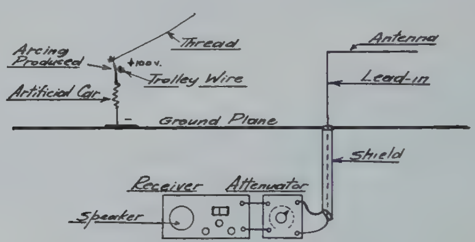

Fig. 7—Vertical cross section of model.

to the paper. Any desired value of resistance, inductance, and capacitance could be used for the artificial car and the sparking trolley wheel was simulated by pulling the thread as shown. The resulting noise from the receiver was then referred to the threshold of audibility by a calibrated attenuator. Any desired impedances could be connected to the model as terminations or loading to reproduce any condition that required investigation. The following are observations from the tests:

1. The severity of the interference depends directly upon the magnitude of the current broken until the current becomes so large that the rapidity of the break is decreased by the follow-through of the arc.

2. The greater the load on the system the less interference a given car can cause.

3. The position of the car relative to the receiver is unimportant. A car located a mile distant can cause as much interference as one a block away. Note the low attenuation constants in Table II.

4. The up-lead portion of the antenna picks up about 75 per cent of the interference received.

5. Moving the antenna perpendicular to the trolley makes only a 10 per cent improvement over the parallel position.

6. Foreign circuits may reduce the interference or increase it, depending upon the existence of parametrical similarity in the circuits.

7. Two possible though impractical, solutions exist:

(a) Sectionalize the system by the installation at frequent intervals of an impedance equal to the characteristic impedance of the system so that no reflections or transmissions of traveling waves will take place.

(b) Sectionalize the system frequently by section breakers, feeding each section from an underground cable. The sections would have to be short enough to make their natural frequency above the important radio frequencies.

Acknowledgment

The writer wishes to give recognition to the valuable assistance given to this study by McGill University, Montreal Tramways Company, and the Radio Branch of the former Canadian Department of Marine.

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NICKEL IN THE RADIO INDUSTRY*

By
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De Forest employed platinum for the grid and plate of his original triodes but after trials of other metals chose nickel as the most suitable metal for commercial production. This metal has been the stand-by of the radio industry ever since. As the art developed, tube engineers found nickel amazingly responsive to their increasingly diverse demands. They could carbonize it, could alloy it to secure low grid emission, and could use it as a base for oxide-coated cathodes.[1] As the demand grew the methods employed for producing nickel likewise improved so that nickel and its alloys are now available in every useful form and at a cost which is as low as is compatible with the high quality essential to the industry.

The amount of nickel required for the internal parts of a tube is surprisingly small, only about four grams in the average radio tube and the primary cost of the nickel is but a fraction of a cent per tube. This cost is small in comparison with the shrinkage losses which would result if less suitable materials were employed.

The intrinsic properties of nickel which render it so generally applicable to the construction of radio tubes will be discussed in detail but before doing so, it is thought that a brief outline of the method employed in the production of the refined metal and the finished strip and wire might be of interest.

The Sudbury ores, which are the principal source of nickel, contain nickel, copper, iron, and sulphur, plus small percentages of precious metals. Part of the copper is removed by selective flotation and most of the remainder by fusion with sodium sulphide which dissolves copper but not nickel sulphide. The bulk of the sulphur and iron is removed by oxidation. The semipurified metal is cast into anodes which are electrolyzed in a diaphragm cell, where the nickel is dissolved but the precious metals remain unattacked and are recovered. The solution resulting from the dissolving of the anode is withdrawn and chemically purified to remove all traces of iron and copper. The highly purified solution, which is really a high grade nickel plating bath, is

* Decimal classification: R282.1. Original manuscript received by the Institute, March 9, 1937; revised manuscript received by the Institute, April 26, 1937. Presented before Rochester Fall meeting, November 18, 1936.
[1] Numbers refer to Bibliography.

then pumped into the cathode compartment of an electrolytic cell where it deposits nickel of very high purity on a thin nickel "starting sheet." The resulting cathode nickel, which constitutes the melting stock for all radio nickel contains upwards of 99.95 per cent Ni +Co; indeed a recent analysis shows a value of 99.97 per cent Ni +Co, the impurities being Fe 0.01 per cent, Cu 0.01 per cent, and S 0.001 per cent.

The melting of so pure a product without serious contamination from either the refractories, the slag, or the furnace atmosphere is no simple matter, but that it can be done is evident from the analysis of commercial "A" nickel. The melted cathode nickel is subjected to special refining operations while held in the furnace to reduce the gas content to a very low level. Finally, a fraction of a per cent of magnesium is added to secure maximum malleability and other essential characteristics. Ingots weighing 7200 pounds are then cast and sampled for chemical analysis. The ingots are milled, hot-forged, repeatedly resurfaced to remove any imperfections and are then hot-rolled to a ⅛-inch strip which is annealed, thoroughly pickled and inspected. After trimming, this strip is accurately cold rolled to 0.045-inch thickness and subjected to a special continuous anneal in a hydrogen atmosphere.

The 0.045-inch annealed strip is supplied to the several rerollers who cold-roll it, with suitable intermediate hydrogen anneals, to the dimensions required. The intermediate anneals and rolling reductions are selected to develop the properties required to meet the special needs of their customers. Considerable cropping and trimming are required throughout the processing with the result that the yield of finished strip is less than 50 per cent of the initial weight of the ingot.

Seamless tubing to be redrawn into cathode sleeves is produced in the same general manner. Heats selected on the basis of a special check analysis with Mn, Cu, and Fe limited to 0.2 per cent or below, are hot-pierced into $3\frac{1}{2}$-inch outside diameter tubes which are redrawn with numerous anneals to $\frac{7}{8} \times 0.065$-inch wall tubing. This is then redrawn by the tube drawers into the 0.040- to 0.050-inch outside diameter by about 0.002-inch wall cathode sleeving after special test to insure high cathodic activity.

The methods used in producing wire rod are much the same as those employed for the other products and the material is finally hot-rolled to ¼- or 7/32-inch diameter rod which is annealed, pickled, and given a lime coat after which it is redrawn through tungsten carbide and diamond dies, with suitable intermediate anneals in a controlled atmosphere. The annealing is adjusted to meet the applications for

which the wire is intended. In some cases rather special processing is required to meet the special requirements of grid and certain support wires.

Rigid attention must be given throughout all heating, rolling, and drawing operations to avoid all contamination, particularly from traces of sulphur which would impair the product. These requirements and the necessity for producing highly finished strip have done much to stimulate the development of improved processing equipment, particularly annealing equipment.

A typical analysis of "A" nickel strip as supplied for rerolling is shown in Table I.

TABLE I

	Per cent
Ni+Co	99.45
Fe	0.13
Mn	0.11
Cu	0.07
Si	0.07
C	0.11
S	0.005

Because of the employment of hydrogen anneals between rerolling operations and particularly in redrawing, some reduction in carbon content will normally occur and values as low as 0.02 to 0.04 per cent are not unusual in strip while in products such as cathode tubing the final carbon content may become even lower.

Properties Required in a Metal for Vacuum Tubes

A surprising number of properties are of direct importance to the manufacturer and user of tubes and other radio equipment.[1] These may be grouped in various ways, but for convenience we have chosen to classify them into mechanical, thermal, electrical, and chemical properties, and to discuss the bearing of these properties upon the behavior of individual parts of the vacuum tube.

While the properties of nickel in so far as they bear on the radio art, are our primary concern, comparative data relating to iron have been included in some instances, in view of the claims which have been made for it.

A. Mechanical Properties

1. The strength and ductility must permit easy forming, drawing, bending, notching, and peening, while the fully annealed material must be sufficiently strong to permit handling during assembly and maintain proper alignment during use.

2. Strength must be retained at high temperatures to avoid de-

formation during bombardment and use. This is important in grids, plates, and support wires.

3. The modulus of elasticity and the damping factor should be high to minimize vibrational displacements which cause microphonic effects.

4. The production of strong reliable spot welds must be readily accomplished, as good welds are essential to reliability.

B. Thermal Properties

1. A reasonably low coefficient of thermal expansion is desirable, while freedom from discontinuities in expansion or structural transformations which may tend to cause warping is of equal importance.

2. Very low expansion, and sometimes expansion curves of special shape, are required for metal-to-glass seals.

3. An adequate thermal conductivity at operating temperatures is essential, particularly in plates and grid side rods, to avoid hot spots and to decrease back emission.

4. A high reflectivity for thermal radiation is required in cathode shields in gas tubes and is desirable in plates for low filament current tubes, while a moderately low thermal emissivity is desirable in hot cathodes to minimize heat losses by radiation.

5. It must be possible to develop a high thermal emissivity by carbonizing to maintain low plate temperatures.

6. The vapor pressure at outgassing temperatures must be low to prevent sublimation.

7. The melting point must be well above the outgassing temperature and the outgassing temperature should be considerably higher than the operating temperature.

C. Electrical Properties

1. A moderate electrical conductivity is generally desirable. Too high a conductivity makes welding and induction heating difficult or impossible, while an excessively low conductivity is objectionable in current carrying leads. In resistors a high resistivity and low temperature coefficient are required.

2. For electrical contacts in base pins, switches, etc., a low contact resistance is required to maintain quiet operation. This requires good corrosion resistance and in some cases appreciable hardness to resist wear.

3. The metal must afford a satisfactory base for oxide-coated cathodes.

4. The coated metal must be effective as a cold cathode.

5. Conversely, in grid wires and carbonized plates, it is essential that the metal emit a minimum quantity of secondary electrons and be as poor a cathode as possible to minimize back emission.

6. The magnetic properties are generally unimportant in radio tubes, but freedom from magnetic effects may be desirable in portions of cathode-ray tubes. In transformer cores and magnetic shields, magnetically soft materials are required, while in permanent magnets the reverse is demanded.

D. Chemical Properties

1. Resistance to oxidation at elevated temperatures is highly desirable for it avoids many processing difficulties.

2. Freedom from any tendency to rust in the atmosphere is extremely important, as is good resistance to corrosion by the chlorinated degreasing solvents, for corrosion products of any sort introduce troublesome impurities into the tube.

3. The gas content must be low and the metal must outgas readily during bombardment.

E. Commercial Requirements

1. The product must permit the smooth production of quality tubes with minimum shrinkage and yield tubes of excellent performance.

2. The metal must be of such a nature as to permit modification of its properties by alloying elements to fit special situations.

3. It is further essential that the metal be available from reliable sources in the varied forms required and at as low a cost as is consistent with quality. It is also essential that close co-operation be maintained with the user to insure that his special requirements are known and met.

Mechanical Properties

Strength Properties at Room Temperature

"A" nickel can be hardened by cold-rolling or cold-drawing, and the cold-worked material can be softened by annealing. By properly adjusting these operations the properties can be altered over the required range.

The relation between the hardness and tensile properties of previously cold-rolled 0.005-inch "A" nickel strip and the annealing temperature is shown in Fig. 1.* The microstructures of some of these

* The proportional limit is the maximum stress within which the strain is proportional to the stress; i.e., the limiting stress below which Hooke's law applies.

The yield strength corresponds to the stress causing a specified departure

samples are shown in Fig. 2. As will be noted, the strength properties can be altered over a wide range by changing the annealing temperature, but for most radio purposes material possessing a tensile strength of about 60,000 pounds per square inch is desired.

It may be noted that as nickel is stretched, it does not exhibit a sharp break at the yield point and is free from any tendency to develop rough strain lines or "stretcher strains" which are sometimes observed with iron and soft steel.

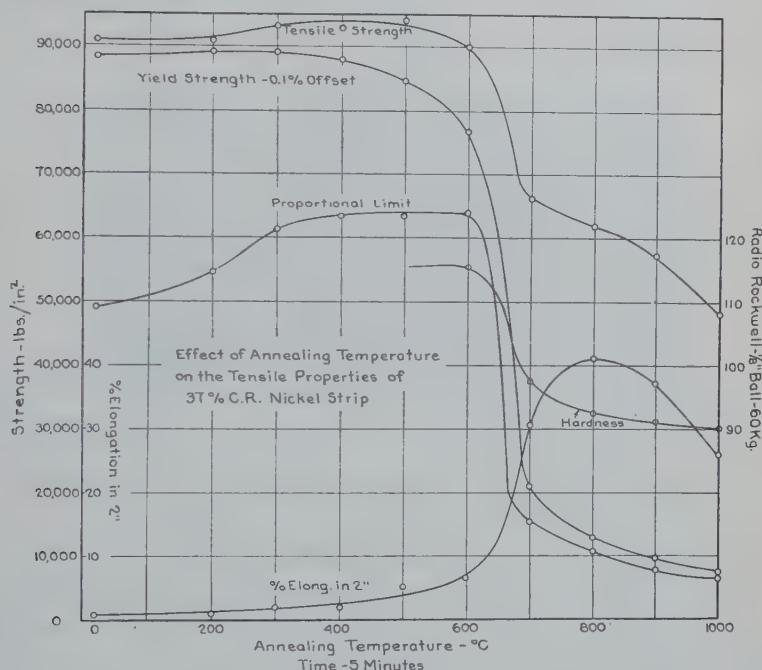


Fig. 1

A species of Rockwell hardness test, herein termed Radio Rockwell, employing a stack of test strips (0.040 inch high composed of eight 0.005-inch strips) with a ⅛-inch ball and 60-kilogram load, has found considerable application in testing radio strip. The hardness values obtained by this method are shown in Fig. 1. While this test is less discriminating than the tensile test, it is rapid and has been quite use-

(0.1 per cent of the gauge length in the present case) of the strain from a line tangent to the portion of the stress strain curve below the proportional limit.

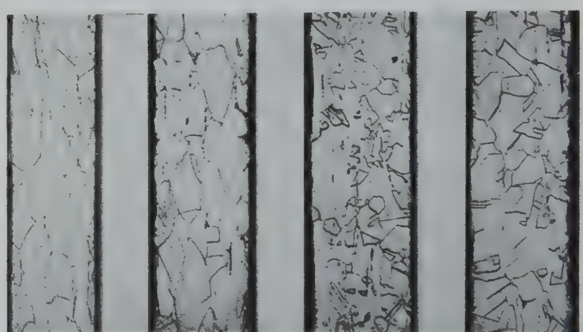
The tensile strength is the maximum stress, computed upon the original area of the test piece, observed while straining the material to rupture.

The elongation represents the extension, expressed in percentage of the original gauge length, which the material exhibits on being strained to rupture.

For further details, see reference (53).

ful in checking material. It must be noted that this test does not give numbers corresponding to the normal Rockwell figures on heavier sheet which are obtained under quite different test conditions.

Other methods of test, mutually agreed upon by buyer and seller, are also in use including cupping tests such as the Erichsen and Olsen, which are principally useful in affording a check on grain size, particularly in deep drawing stock, and various bend tests, dynamic and static.[2] The latter find their principal application to wire for grid side rods where extremely soft material is required to facilitate notching and peening and thus increase the "life" of the grid machines.



As received 600°C. 700°C. 800°C.

Fig. 2—Photomicrographs of cold-rolled nickel, as rolled and after annealing for five minutes at various temperatures. 0.005-inch strip—100 ×.

The Mechanical Properties of Specially Alloyed Nickels

In certain instances "D" nickel containing 4.25 to 5 per cent manganese rather than "A" nickel is employed for support rods. The strength properties of this alloy when fully annealed are slightly above those of "A" nickel and its annealing temperature is higher which results in the retention of somewhat greater hardness after mounting.

Where very high strengths are required a special type of nickel designated "Z" nickel (containing nearly 99 per cent Ni +Co) is produced which may be hardened by heat treatment at 500 to 600 degrees centigrade to develop a tensile strength of about 160,000 pounds per square inch.

Strength at High Temperatures

To be satisfactory for tube parts the metal employed must remain strong at elevated temperatures and be free from any tendency to warp or suffer permanent dimensional change on heating, for temperatures as high as 1050 degrees centigrade may be reached during outgassing

or bombardment while oxide-coated cathodes operate at temperatures as high as 950 degrees centigrade in large gas or mercury-vapor tubes,

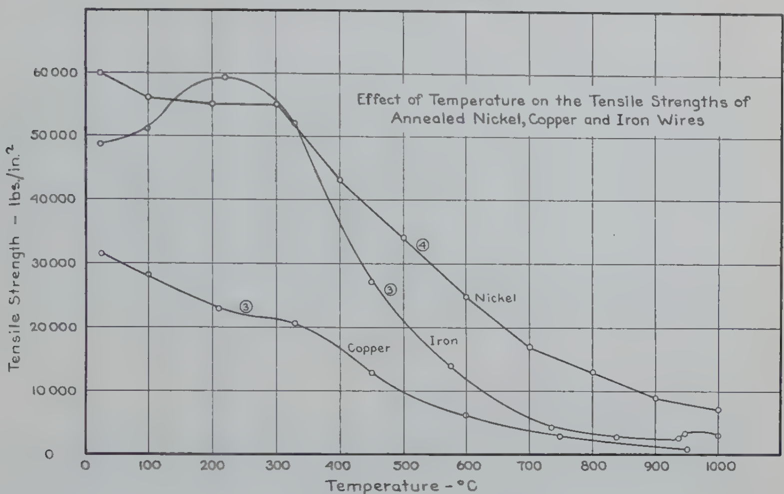


Fig. 3

and at about 750 degrees centigrade in small tubes. The grids also attain high temperatures during bombardment and run fairly hot as do many types of plates. Distortion will cause a change in tube constants

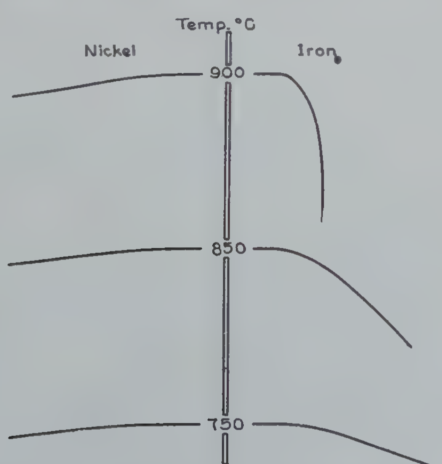


Fig. 4—Cantilever beam test. All specimens held five minutes at temperature.

and is troublesome in other ways, so that it is essential that a material be used which does not deform or flow readily at these high temperatures.

Some indication of the useful strength at high temperatures can be obtained by determining the tensile strength at these temperatures. The values observed by Jeffries[3] and Sykes[4] for annealed "A" nickel, iron, and copper wires are shown in Fig. 3. The hump at 250 degrees centigrade in the curve for iron is probably due to oxygen in the metal. Other tests to determine the relative bending of short strips of nickel and iron show that iron practically wilts at 900 degrees centigrade, whereas nickel at 900 degrees bends less than iron at 750 degrees centigrade, as shown in Fig. 4. Other tests at 730 degrees centigrade, show that nickel will support fifteen times as much load as iron for the same (small) sag. Long-time creep tests conducted by Austin and Gier[5] at 680 degrees centigrade prove that very pure nickel will carry five times as much load as pure iron for the same (low) rates of creep.

Strength Requirements in Grid Wires

High hot strength is an important requirement for grid wires, and is essential to prevent sagging and warping and hence wandering tube constants; a second requirement, which will be discussed in a subsequent section, is freedom from back or secondary emission. Others are good ductility, uniform spring back, low thermal expansion, and moderate cost. A great deal of work has been done on this problem by tube engineers and metallurgists, which has resulted in the general adoption of a limited number of alloys. "D" nickel containing 4.25 to 5 per cent manganese is probably the most widely used, followed by the 60 per cent nickel, 20 per cent iron, 20 per cent molybdenum; and 85 per cent nickel, 15 per cent chromium alloys, and pure molybdenum. Each of these materials has a useful field, so that quite frequently a multigrid tube will contain several types of grid wire.

Stiffness or Modulus of Elasticity

Microphonic effects in tubes are due to the elastic displacement of the parts. The amount of displacement for a given force and design varies inversely with the modulus of elasticity of the metal used for the structure. For this reason, a high modulus is desirable. The tensile (Young's) modulus of annealed nickel is 30,400,000 pounds per square inch, that of iron is slightly lower, while the modulus of copper is only about half that of nickel. The modulus of certain high nickel alloys is appreciably raised by cold working.

The ability of nickel to damp mechanical vibrations is also helpful in reducing microphonics. Recent determinations by Förster and Köster on annealed pure metals give the following values for damping

coefficient $\times 10^{-4}$: nickel 72.1, iron 5.6, molybdenum 5.1. The high damping coefficient of nickel as compared to other metals is striking.

Spot Welds

The spot-welding characteristics of nickel result from a fortuitous combination of properties, including resistance to oxidation, which minimizes sparking and preserves a good appearance, toughness of the weld metal, freedom from embrittlement on subsequent heating in hydrogen, and high strength at elevated temperatures, reducing squashing under the electrode. Nickel welds readily to other metals

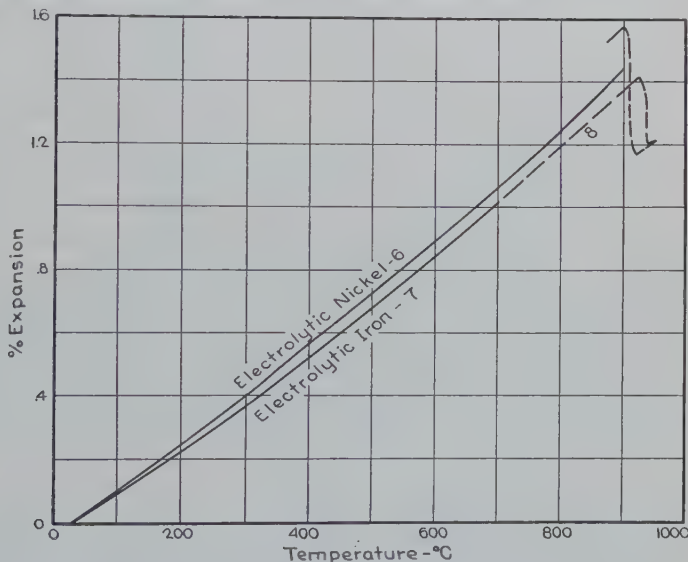


Fig. 5—Thermal expansion of nickel and iron.

including Dumet and molybdenum, both of which are useful for lead-in wires. The absence of any carbide forming tendency in nickel prevents brittleness in welds to carbonized surfaces. The electrical resistance of nickel is sufficient to develop adequate heat without excessive electrode wear; metals of excessively high conductivity are notoriously difficult to weld and the resulting welds are unreliable. In view of the multitude of spot welds required in radio tubes, the satisfactory welding properties of nickel are of substantial value to the industry.

Thermal Properties

1. Thermal Expansion

The length versus temperature curve for pure nickel is shown in Fig. 5.[6] As will be noted, the coefficient of expansion varies only

slightly with the temperature and no discontinuous length changes exist. At low temperatures the curve for iron[7] differs but little from that of nickel, but at 910 degrees centigrade an abrupt shrinkage occurs which is followed by a period of high expansion. This is due to the fact that the crystal form of iron becomes unstable at this temperature causing the iron to transform from the body-centered cube form to the face-centered type. This does not occur with nickel, which remains face-centered cubic at all temperatures. This abrupt shrinkage in iron, coupled with its low hot strength stimulates warping and deformation.

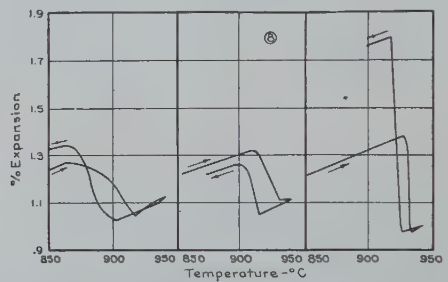


Fig. 6—Changes in length of iron on passing through α–γ transformation.

As a matter of fact, as shown by Austin and Pierce,[8] even small rods of pure iron undergo a considerable but unpredictable change in length on being heated and cooled, and do not return to their original length on cooling, as is shown in Fig. 6.

2. Low or Special Expansion Characteristics

Where a very low thermal expansion is required at moderate temperatures, or where expansion curves of special shape are required as in glass-to-metal seals, a series of nickel-containing alloys is available. These alloys range from Invar, with about 36 per cent nickel, to 52 per cent nickel-iron, and Dumet, containing a core of the 42 per cent nickel alloy and a sheathing of copper, to the more complicated nickel-iron alloys containing also cobalt, known as Kovar and Fernico which are used for seals in all-metal tubes.

The expansion curves of the more important alloys of this type are presented in Fig. 7.[9,10,11] According to Hull and Burger, the theoretical longitudinal coefficient of expansion of Dumet is about two per cent higher than the radial coefficient, but due to plastic flow of the copper the observed axial (longitudinal) coefficient is much smaller and the radial coefficient much larger than the calculated values. The difference between the longitudinal and radial values is about 40 per cent. Dumet is universally used for seals through soft glass, whereas

the more complicated alloys are used as eyelets in the hard glass seals, in conjunction with molybdenum leads while tungsten is also used for seals to "Nonex" glass. The 50-50 nickel-iron alloys are used, particularly abroad, for glass-to-metal seals in large water-cooled tubes in preference to the copper-to-glass (Housekeeper) seal. Gas-tight joints can be made with either material, but the softness of the copper and

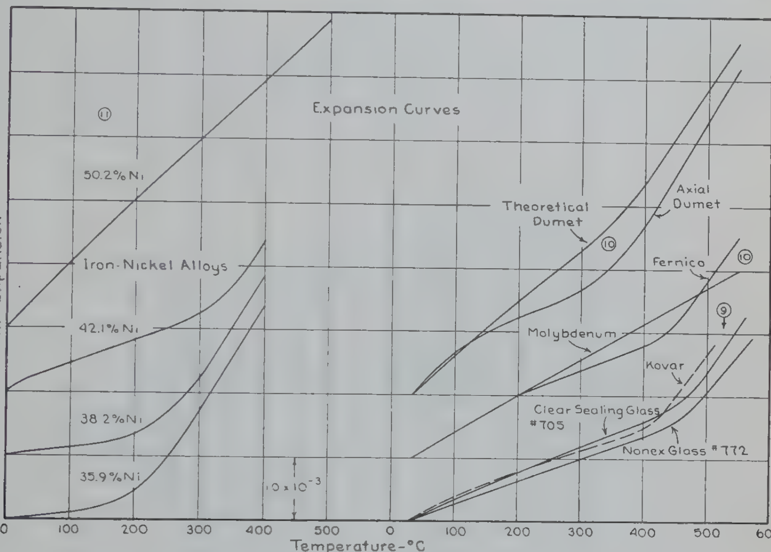


Fig. 7

its oxidation during baking are objectionable as is its tendency to fail by fatigue on repeated heating and cooling. Copper is attacked by mercury making it unsuitable for tubes containing this metal.

3. Thermal Conductivity

The thermal conductivity of two samples of nickel[12] has been determined at a series of temperatures at the National Bureau of Standards. The results are presented in Fig. 8, together with those for two samples of iron.[13] The thermal conductivity of the purer nickel sample is 8.3 watts per centimeter per degree centigrade at 100 degrees centigrade and is about 25 per cent higher than that of the corresponding iron sample. Above 360 degrees centigrade (the Curie point) the thermal conductivity of nickel increases with temperature while that of iron continues to fall, so that at 550 degrees centigrade the thermal conductivity of nickel is almost 50 per cent higher than that of iron. The change in the direction of the thermal conductivity curve of nickel at about 360 degrees centigrade appears to be associated with a

change in the electron spins which is also responsible for the change in magnetic properties at this temperature. This increase in the thermal conductivity of nickel at elevated temperatures is of importance in preventing hot spots in plates and other parts and thus tends to reduce back emission.

4. Thermal Reflectivity

A high reflectivity for the long-wave radiation emitted from hot cathodes is important in the heat-conserving shields surrounding the cathode in high current gas or mercury-vapor tubes. It is also of some consequence in the plates of smaller tubes such as the "30" where

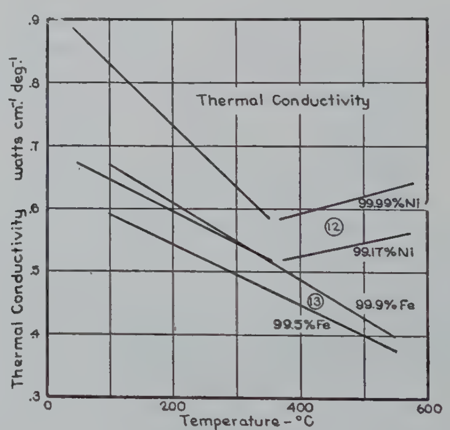


Fig. 8

every effort is made to conserve filament power so that even the small aid offered by a reflective plate is worth while. The inversely related function, thermal emissivity, should be low for cathode base metals to reduce the amount of heat lost from the cathode. A high thermal reflectivity is also desirable in grids to reduce the amount of heat absorbed.

The reflectivities of nickel[14] for radiation of the long wave lengths of importance with medium temperature radiators are given below.

($\mu = 0.001$ mm.)

	2μ	3μ
Nickel	83.5%	87%

From these values it is evident that the thermal emissivity of nickel cathodes is low. The emissivities determined by B. T. Barnes[55] are shown in the lower portion of Fig. 9.

5. Methods for Increasing the Thermal Emissivity of Plates

In all but small tubes with low plate dissipation it is generally necessary to use a plate of high thermal emissivity. Attempts have been made to use oxide coatings to accomplish this, but it turns out that some visually dark oxide coatings are fair reflectors of long-wave radiation, and hence are far inferior to a black body radiator. In addition, trouble is sometimes encountered through the reduction of the oxide coating during service, yielding oxygen and ruining the tube.

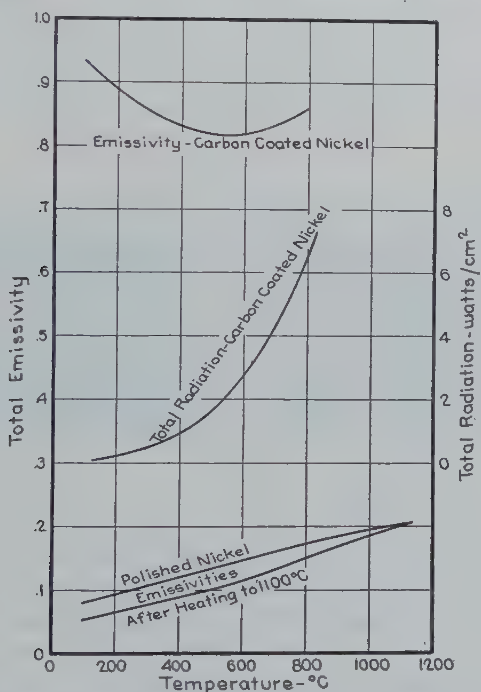
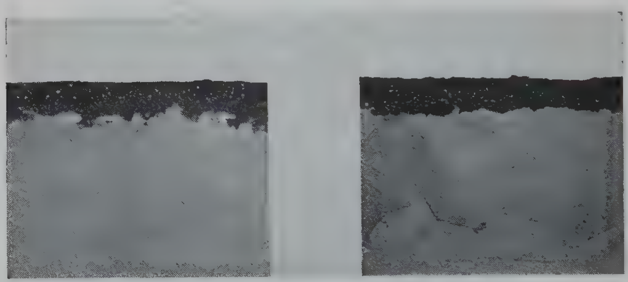


Fig. 9—Radiating characteristics of plain and carbonized metal.[55]

Aside from molybdenum, tantalum, and graphite, which find application in large radiation cooled tubes, the general and satisfactory answer to the plate problem is to deposit an adherent layer of carbon from a suitable hydrocarbon gas upon the surface of nickel. In practice, it is usual to oxidize the nickel slightly prior to the carbonizing operation, and to use sulphur-free natural gas or a mixture containing propane as the source of carbon. This oxide is reduced by the hot hydrocarbon gases employed in the actual carbonizing operation and yields a catalytically active surface which greatly facilitates the deposition of a uniform adherent coating of carbon. This treatment suffices for

parts carbonized after forming, but where carbonized strip is produced to be subsequently formed into plates the strip is sometimes sandblasted prior to oxidation and carbonizing. In close-spaced rectifiers a smooth surface is desired adjacent to the cathode so that only one side of the strip is sandblasted in this case. Since the microstructure of precarbonized strip is of some interest, an example of it is shown in Fig. 10.

Nickel is the only metal suitable for this process because its catalytic influence in cracking the carbon containing gas yields a good adherent coating of carbon and because it does not form carbides and become brittle as a result of this drastic treatment. The high hot strength of nickel also minimizes the warping and deformation incidental to the process.



Unetched Etched

Fig. 10—Photomicrographs of carbonized nickel strip—250 ×.

The requirements of manufacturers differ slightly regarding the type of carbon desired, so that coatings ranging from rather hard dark grey to the softer extremely black coatings are produced by adjusting the carbonizing conditions. The thermal emissivity of these coatings will differ slightly with the type but will be of the order of 80 per cent or higher. The emissivity of carbon-coated nickel and the total radiation from such a surface as determined by Barnes[55] are shown in Fig. 9.

In addition to the useful effect of carbon in increasing the thermal emissivity and thus lowering the plate temperature, the back emission is further lowered by the tendency of the carbon surface to combine with any sublimed barium and thus render it inactive as an electron emitter.

6. Vapor Pressure

The effect of temperature upon the vapor pressure of nickel as determined by Jones, Langmuir, and Mackay[15] is presented in Fig. 11. These workers also present data on the corresponding mass rates of

evaporation in vacuo, however in practice the volume rates (cubic centimeter per square centimeter per second) are more pertinent, hence these values are presented. It should be borne in mind that the latter rates will be greatly lowered in gas-filled tubes.

Both rates are low at tube operating temperatures for the hottest part, the cathode, operates at 750 degrees centigrade to possibly 800 degrees centigrade in vacuum tubes and at 950 degrees centigrade in industrial gas or mercury-vapor tubes, but are of consequence at high bombarding temperatures which may reach temperatures of the order

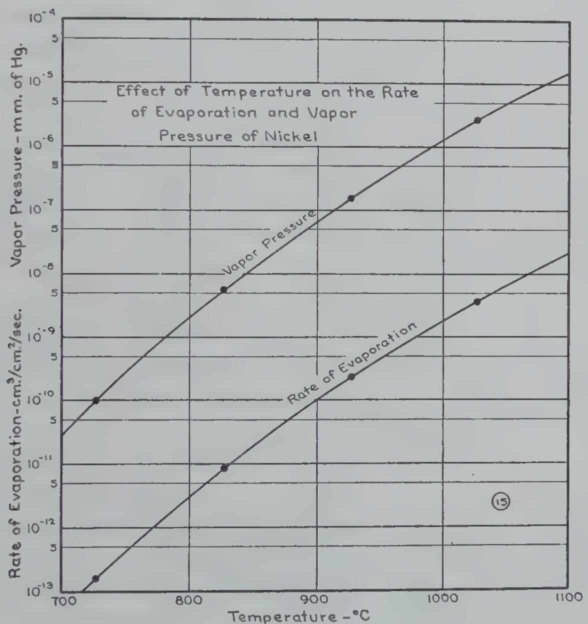


Fig. 11

of 1050 degrees centigrade. The limitation in this case is not due to damage to the nickel but rather to the sublimation of traces of metal upon near-by insulating elements, which becomes of consequence at temperatures above this.

These same investigators studied a number of other metals, and found the vapor pressure of iron to be slightly higher than that of nickel whereas the vapor pressure of copper was about ten to fifteen times as high as nickel.

7. Melting Point

The melting point of nickel is 1728 degrees Kelvin (1455 degrees centigrade)[6] which is far above any temperature attained during

bombardment or use in small tubes, except heaters for indirectly heated cathodes, for which tungsten is employed.

Electrical Properties

1. Electrical Resistivity

The resistivity of nickel at room and elevated temperatures is such that welding is readily accomplished and induction heating is easily effected, yet it is low enough to render nickel suitable for current carrying leads and for allied applications.

The electrical resistivity and temperature coefficient of resistivity of nickel have been determined by a number of investigators and a few representative data are shown in Table II.

TABLE II

Type of Nickel	Resistivity Microhm-centimeters	Temperature Range	Temperature Coefficient per Degree Centigrade
	Determined by Stanton Umbreit, RCA[20]		
Electrolytic (Not Fused)* 99.98–99.99% Ni	R_0 6.141	0–100°C.	0.00682
	R_{20} 6.844 R_{100} 10.327		
After vacuum firing 30 min. 1050°C		0–100°C.	0.00692
	Determined by National Bureau of Standards[6]		
High Purity 99.94% Nickel (2) (Melted and Forged)	R_{20} 7.236	0–100°C.	0.0067
	Determined by Hunter, Sebast, and Jones[17]		
Electrolytic (Not Melted) 99.8 Ni+Co	R_{20} 7.55–7.60	20–50°C.	0.00559–0.00553
	Determined by E. F. Bash, Driver-Harris[19]		
"A" Nickel Av. (Commercial Wrought Nickel)	R_{20} 10.45 Range 9.48 11.33	20–50°C.	0.0041–0.0051

* Prepared by W. A. Wesley, Research Laboratory, The International Nickel Company, Inc.

As is characteristic of metals the first small additions of Co, Mn, Si, Mg, etc., cause a marked increase in resistivity and a drop in temperature coefficient whereas further amounts of addition elements produce a less marked effect. For example "D" nickel possesses a room temperature resistivity only about twice that of "A" nickel, despite the large amount of manganese (about 4.65 per cent) present. At higher temperatures the effect of alloying elements is relatively less than at room temperature as is shown in Fig. 12 and is a characteristic which must receive consideration in the design of directly heated cathodes in those instances where the room temperature resistivity is employed for inspection tests. For a theoretical treatment reference (54) should be consulted.

Where a high resistivity and a low temperature coefficient are required as in resistors, voltage dividers, and the like, a host of nickel content alloys are available including the ferro nickels, the copper nickels containing 40 to 45 per cent nickel or 67 per cent nickel, and the chromium nickel and chromium nickel-iron alloys with from 15 to 20 per cent chromium. The characteristics of these alloys are so well known that they need not be discussed here.

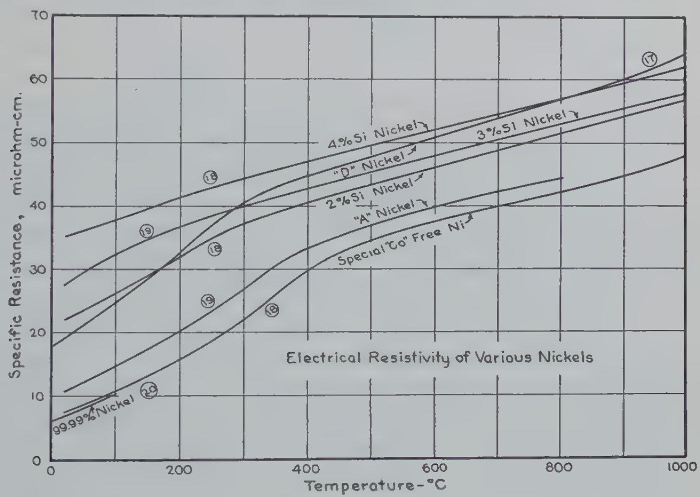


Fig. 12

2. Electrical Contacts

Solid nickel has found considerable employment in sliding electrical contacts, particularly in electrical instruments where resistance to corrosion and wear must be had. Nickel electroplate is also widely used for surfacing contacts such as tube base pins and the like where only a small amount of wear is involved. However, methods are now available for depositing nickel with a hardness of about 400 Brinell and this may have application in radio switches where resistance to wear is a consideration.

Palladium, platinum, and the platinum content gold alloys are widely used for contacts in small relays handling up to about 0.6 to 1. ampere where the ability to function for long periods without developing a high or electrically noisy contact resistance, or serious erosion are primary requirements. Frequently, the ability of these materials, particularly platinum, to function with very low contact pressures is particularly useful. The general employment of palladium contacts in telephone relays contributes to the quietness of every program network and telephone conversation.

Silver finds employment in relays of certain types, particularly those handling considerable current and where rather high contact pressures can be employed. Tungsten is used for medium currents, particularly where the contacts close with considerable impact; the impact sufficing to knock off the oxide which would otherwise be troublesome.

Other nickel alloys, particularly Monel and 18 per cent nickel silver (German silver) are frequently employed to support electrical contacts because of their good spring properties, corrosion resistance, and excellent spot-welding characteristics.

3. Hot Cathodes

While the exact mechanism involved in the emission of electrons from the oxide-coated cathodes discovered by Wehnelt[21] is still in dispute, it appears certain that some reduction of barium (and probably strontium) from the oxide coating does occur when reactive elements are present in the nickel core and is helpful in securing an active cathode. It is also clear that some further liberation of barium results from the electrolysis of the coating during normal use. The desirability of having small amounts of slightly reactive elements in platinum base oxide-coated cathodes has been known for some years; while the work of Lowry, the more recent work of Benjamin[22] and much unpublished work have demonstrated that small amounts of Mg, Si, Ti, and Al in the nickel core are effective in activating oxide-coated cathodes. For a general discussion Reimann's[23] book may be referred to.

Due to the fact that "A" nickel, which is generally used for cathode sleeves, and yields excellent cathodes, contains traces of activating elements such as Mg and Si, it seemed desirable to determine whether an oxide-coated cathode utilizing a nickel completely free from reducing elements would show appreciable activity. Accordingly, a sample of nickel possessing a purity of 99.99 per cent was prepared in this laboratory and coated and tested through the courtesy of a leading radio tube research laboratory.[24] Cathodes of several types were made up and while some emission was obtained it was only 30 to 80 per cent of that normally obtained and a power emission test showed only one per cent of the usual value.

Thus, it appears that while commercial coatings applied to substantially pure nickel cores yield some emission, this may have been due to traces of reducing elements in the coating vehicle. In any event, these observations indicate that the commercial nickels are decidedly superior to the extremely pure product where the prompt development of an active cathode is essential.

Since this work was done Benjamin[22] has reported the behavior of

oxide-coated cathodes utilizing a series of low alloy content nickel cores, but unfortunately none of these represented the standard type

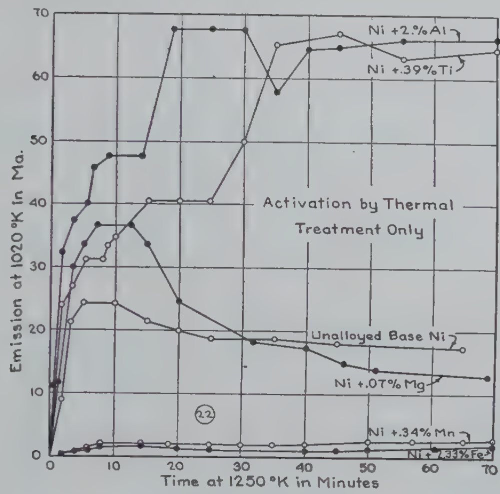


Fig. 13—Activation by thermal treatment.

of "A" nickel. The less active pure nickel which he employed for comparison apparently contained 0.006 per cent Mg, 0.016 per cent Si, and probably 0.013 per cent Ca and 0.024 per cent Al. The Mg and Si con-

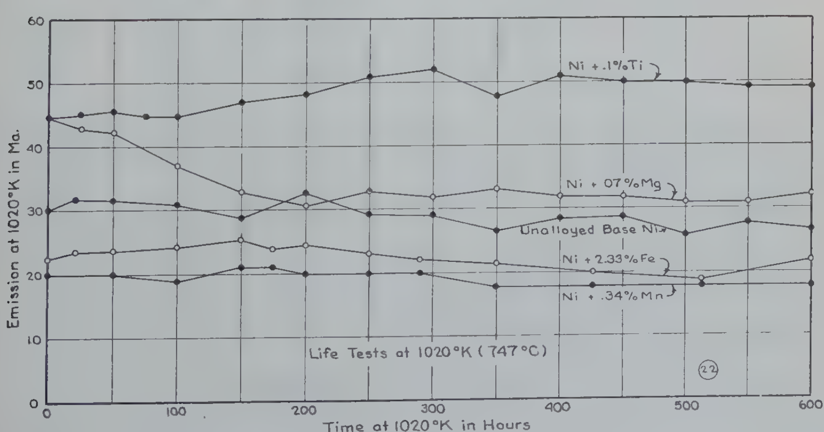


Fig. 14—Life tests at 1020 degrees Kelvin (747 degrees centigrade).

tent of commercial "A" nickel is considerably above this and would be expected to yield activities corresponding with some of his alloyed nickels.

A number of these cathodes containing small amounts of reactive elements in the core develop high activity by purely thermal treatment, as is shown in Fig. 13. In these experiments the two per cent Al nickel and the 0.39 per cent Ti nickel appear to yield the most active cathodes; while the "pure" nickel (which was not strictly free from reactive elements), and the 0.07 per cent Mg nickel showed some initial activity which decreased on longer flashing at the high temperature employed (1250 degrees Kelvin). The nickels containing manganese and iron remained very inactive.

The initial emissions from the normally activated cathodes are summarized in Table III, while the behavior of some of the cathodes

TABLE III

	Average Emission 1020°K. (747)°C. in ma 40 volts on the plate
Pure Nickel*	31.
Ni +0.07% Mg	45.
Ni +0.1% Ti, 0.37% Fe	45.
Ni +0.39% Ti, 1.1% Fe	46. (from curve)
Ni +2.0% Al	50.
Ni +0.34% Mn	20.
Ni +2.33% Fe	22.5

* While the reference is not entirely clear it appears that this nickel was of the following analysis·

		Per Cent
	Ni	99.32
	Co	0.29
	Mn	Trace
	Fe	0.004
	Si	0.016
	C	0.022
	S	0.003
	Mg	0.006
and probably	Ca	0.013
	Al	0.024

on life test at normal operating temperatures is shown in Fig. 14. During these runs small currents were drawn between emission readings. This same type of nickel was used in the preparation of the other alloys, but in some instances, particularly where Ti or Al was present some further reduction of minor elements from the crucible may have occurred. It is also possible that some Al and Si was present in the Fe Ti but no analyses for these possible minor quantities of activating elements were reported.

The watt input was identical for all filaments and it was assumed that their temperatures were therefore identical. In some cases this may not be quite true as it has been found by others that the presence of about 0.4 per cent manganese in nickel caused an increase in thermal emissivity and hence slightly lowered the cathode temperature.[25] Despite this it is believed that the reduction in activity by iron and manganese is largely a direct effect, a view which is further confirmed

by the low back emission characteristic of barium contaminated grid wires containing 4.25 to 5 per cent manganese.

The behavior of several of the cathodes at high aging temperature is shown in Fig. 15. Space currents of about ten milliamperes were drawn between emission readings which caused some electrolysis of the coating and tended to compensate partially for the loss of barium due to volatilization.

From these experiments it might be concluded that titanium, aluminum, and to some extent magnesium, are useful alloying elements in nickel employed as a cathode base. Some users find that cer-

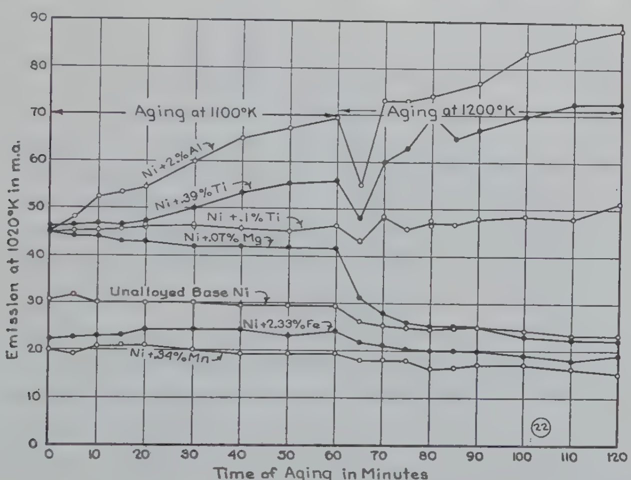


Fig. 15—Behavior at high aging temperatures.

tain activating elements, notably aluminum and silicon, may tend to cause the oxide coating to flake under certain circumstances and for this reason one user prefers to have silicon as low as possible, preferably under 0.05 per cent.

It is unfortunate that selected "A" nickel was not included in these tests for this material, containing as it does small amounts of silicon and magnesium, is the most extensively used cathode base for indirectly and many directly heated cathodes and is known to y eld good cathodes.

A number of low alloy content nickels including those containing aluminum and the special "Z" nickel have been tested in indirectly heated cathodes. Of these only the "Z" nickel appeared to offer possible advantages over the standard selected "A" nickel normally employed in cathodes of this type.

Directly heated cathodes are made of "A" nickel, 3 per cent silicon

nickel, "Z" nickel, 2 per cent aluminum nickel, cobalt nickel and nickel-platinum alloys, the latter materials finding their principal application in small filamentary cathodes which introduce special problems.

For cathodes in tubes designed to have a useful life of the order of 50,000 hours somewhat different requirements must be met and the 5 per cent Ni, 95 per cent Pt alloy has been found most suitable for the core. The use of this alloy in small long life industrial tubes merits consideration; and its extremely high tensile strength at operating temperatures (35,000 pounds per square inch at 750 degrees centigrade) makes it particularly advantageous for very small filamentary cathodes.

The cathode emission in certain tubes such as the "30," which contain very small low current cathodes, appears to be sensitive not only to the presence of very small quantities of alloying elements in the core, but also in the nickel employed for the plate. This has been investigated in considerable detail and the results of many co-operative tests have led to the present type of "A" nickel which is so produced as to afford the best performance in these critical tubes. The use of the same type of nickel in other tubes undoubtedly improves their performance as well.

In passing it may be noted that the work function of a good oxide-coated cathode may be as low as one volt, whereas the work function of clean nickel has been reported to be as high as 5.03 electron volts.[29] The effect on cathode emission is more striking for the oxide coated cathode would emit about 90 amperes per square centimeter at 1000 degrees Kelvin[26] in comparison to only 1×10^{-17} amperes per square centimeter for the clean nickel.

4. Cold Cathodes and Sign Electrodes

Cold cathodes used in electron multipliers function by virtue of secondary emission. The temperature of the cathode is so low that delicate but extremely active surfaces such as caesium on silver oxide similar to those employed in certain photocells can be employed.

The electrodes employed in neon and mercury-vapor signs generally run at temperatures insufficient to develop appreciable straight thermionic emission, but it has been found that nickel electrodes coated with barium and strontium oxides[27] yield markedly lower electrode drops than either blued or barium strontium oxide-coated iron electrodes. Presumably this is due to the ease with which the active nickel electrodes emit electrons by positive ion bombardment, and applies to neon, mercury, and helium content tubes.

The actual electrode drop of the variously coated iron electrodes

is found to be from 30 to 70 per cent higher than that of the above-mentioned nickel electrodes depending on the gas. In addition the voltage drop per foot of tubing may be as much as 65 per cent higher with iron electrodes as compared with active nickel electrodes. Life tests on sign tubes of the neon and neon-argon-mercury type equipped with these oxide-coated nickel electrodes have extended beyond 25,000 hours and are still in progress.[28] Nickel is also used for leads and internal parts of various types of mercury lamps and in other mercury-vapor devices.

In addition to the reduction in voltage drop occasioned by the use of nickel electrodes, their freedom from rusting and low gas content aids materially in the production of good sign tubes.

5. *Means for Securing Low Grid Emission*

Probably the principal source of back emission in grid wires is the barium which unavoidably reaches it from the cathode, for the work function of clean nickel is about five volts[29] and is too high to give rise to appreciable emission. Lowering the grid temperature tends to reduce the thermionic emission from the grid and various schemes are resorted to in accomplishing this, particularly with the control grid. Another and more convenient method is to make the grid from an alloy which remains a poor cathode despite the barium contamination or to apply coatings to accomplish the same result. A fair amount of manganese alloyed with nickel appears to be useful in producing an inactive cathode and the 4.25 to 5 per cent manganese content "D" nickel grid wire is an example of this. Carbon is also very effective in combining with barium and thus rendering it inactive and carbonized nickel grid wire has been produced. While this works, it is too costly for general use in vacuum tubes although applicable to some of the gas-filled tubes. Other methods for producing a carbonaceous coating are more convenient and various special coating methods have been developed by tube makers. It must be recognized that some of these expedients darken the grid wire and thus tend to cause it to absorb more heat; therefore, to be useful the treatment must be sufficiently effective in poisoning the surface to more than compensate for the increased thermionic emission which would otherwise result.

6. *Magnetic Properties*

In normal types of radio tubes the magnetic properties of the metal components are not of consequence, although in cathode-ray tubes the use of even magnetically soft materials in certain parts may be objectionable if the tube be subjected to a strong magnetic field

which may introduce slight residual magnetism causing the electron beam to assume an abnormal location. An alternating-current field can be used to demagnetize the tube if this occurs, or a nonmagnetic material can be employed for the critical parts. Nickel is magnetically rather soft (the pure metal showing a coercive force of 2.73 oersted) and becomes nonmagnetic at the Curie point, which is about 360 degrees centigrade for the pure metal. It should be emphasized that no structural change accompanies this purely magnetic transformation.

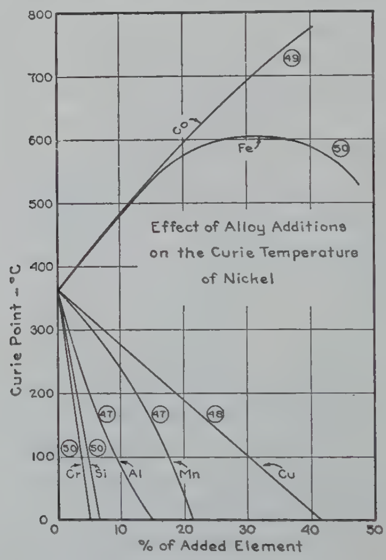


Fig. 16

It happens that the Curie point of nickel is lowered rapidly by several elements, notably chromium, silicon, aluminum, and more slowly by copper and manganese; approximate data are shown in Fig. 16.[47,48,49,50]

If the Curie temperature is below the operating temperature the alloy can be considered to be substantially nonmagnetic. As indicated in Fig. 16 the Curie temperature of nickel can be lowered below room temperature by moderate additions of a number of elements so that several nonmagnetic high nickel alloys can be produced; of these Inconel, a chromium-nickel alloy, and "K" Monel, a copper-nickel alloy containing a small percentage of aluminum, are commercially available and possess excellent properties.

Alloys of high permeability (particularly at low field strengths), low hysteresis, and high resistivity are required for shields, cores of

high fidelity audio transformers, especially input and line-to-grid transformers, reactors and loading coils, certain types of pickups and speakers and are also demanded where weight and space must be saved as in transformers for aircraft.

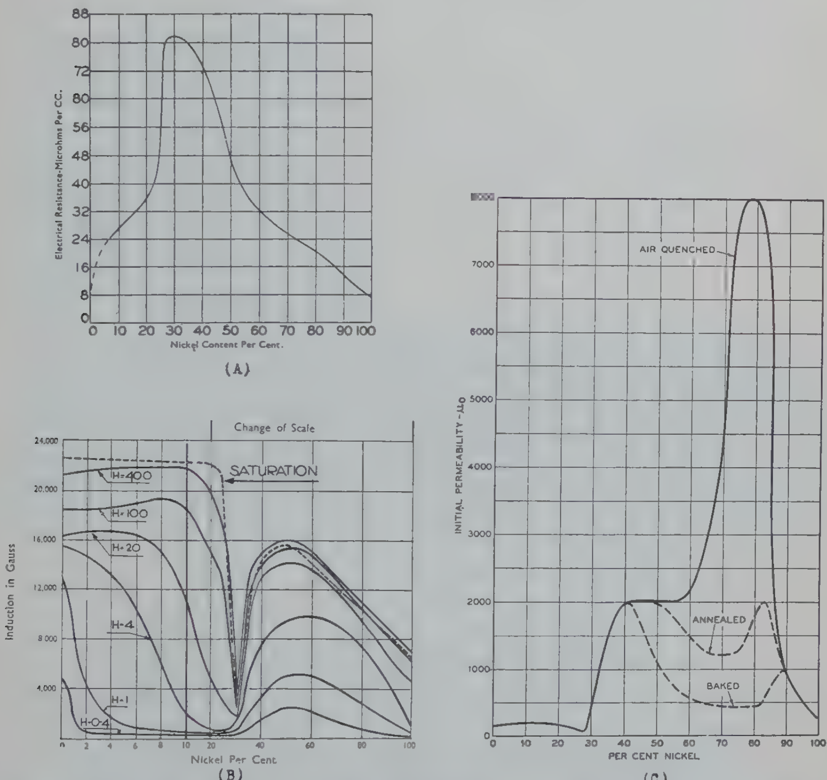


Fig. 17—(A) Variation of electrical resistance with nickel content. (Yensen.)
(B) Variation in flux density at different fields with nickel content in nickel-iron alloys. (Yensen.)
(C) Effect of heat treatment on initial permeabilities on iron-nickel alloys—Elmen.

These essential properties are found in the nickel-iron alloys within the range 45 to 78 per cent nickel and known by various names, including Permalloy, Hypernik, Nicaloi, "A" Metal, Mumetal, etc. Some of the alloys contain small amounts of chromium, molybdenum, or copper, the former two being particularly effective in increasing the resistivity of the higher nickel alloys. The 78 per cent Permalloy and its modifications possess extremely high permeability at low field strength and thus are particularly suited to transformers operating at low energy levels such as input circuits and line-to-grid coupling. The

alloys in the vicinity of 46 to 50 per cent nickel are generally chosen for transformers operating at higher energy levels. Some of the magnetic properties of these alloys are shown in Figs. 17 and 18.[30,31,32,51]

The remarkable saving in size and weight resulting from the use of the 78 per cent nickel alloy is well demonstrated in a recently developed series of extremely small audio transformers. These are about $1\frac{1}{2}$-inches in height and diameter and weigh $3\frac{1}{4}$ ounces but are equivalent in function to a much bulkier silicon iron-core transformer of ten times the weight. The use of this alloy in transformers and loading coils for telephone circuits is well known and is an important contributor to the effectiveness of network hookups.

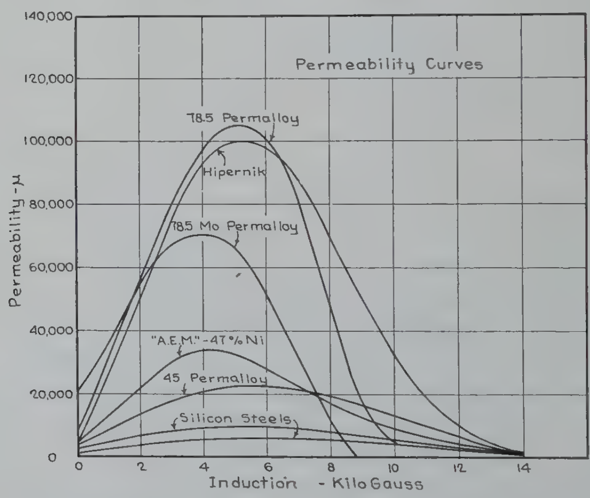


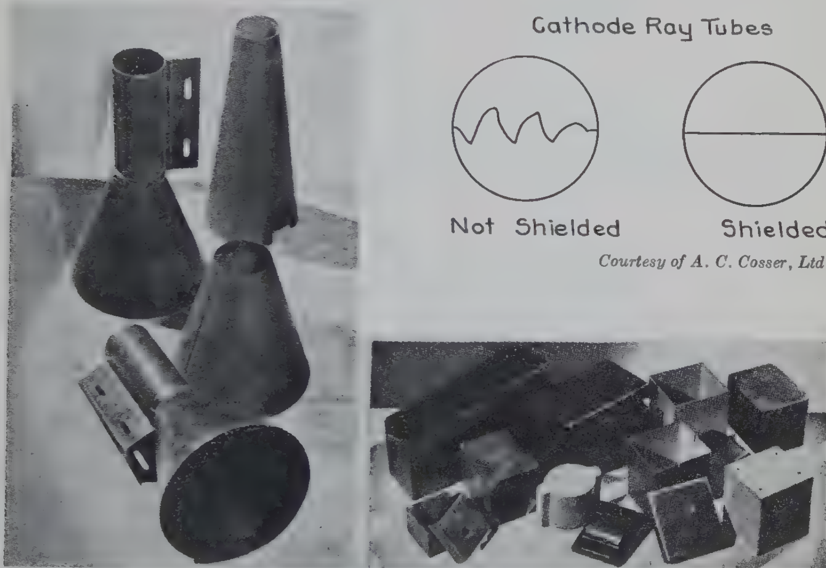
Fig. 18—Permeability curves for various magnetic alloys.

Recent experiments indicate that the nickel-iron alloys are useful for the cores of transformers supplying the grid current in grid controlled mercury-vapor tubes.

Alloys possessing the high permeabilities in weak fields typical of Permalloy, are valuable for magnetic shields, not only to prevent interaction between transformers but also to shield cathode-ray tubes from stray fields, including that of the earth. A few applications are shown in Fig. 19. Further data on magnetic shield materials may be found in the Bibliography.[33,34,35]

In contrast to the foregoing, magnetically hard alloys are required for the permanent magnets employed in certain types of loud speakers, velocity microphones, phonograph pickups, meters, etc. Until recently all good permanent magnets were made of hardened steel sometimes

containing tungsten, chromium, or cobalt, but through the discoveries of Mishima, Ruder, and others, a new type of permanent magnet material is now available with properties exceeding those offered by

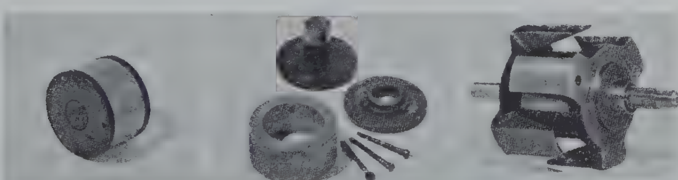


Courtesy of A. C. Cosser, Ltd

Courtesy of Telegraph Construction and Maintenance Co., Ltd.

Fig. 19—Magnetic shields for cathode-ray tubes and transformers.

the best steels. It must be cast or sintered to approximate form and may or may not require subsequent heat treatment, depending upon



Courtesy of The Permanent Magnet Association. *Courtesy of British Thomson-Houston Co., Ltd.*

A B C

Fig. 20—(A)-(B)—Assembled and exploded views of a modern loud-speaker unit incorporating a nickel-aluminum steel magnet.
(C) Rotor for small alternating-current generator incorporating a nickel-aluminum permanent magnet.

the application and method of production. The coercive force is extremely high making it particularly valuable for short magnets. Some applications are shown in Fig. 20.

K. L. Scott has recently given the following values for some of these alloys:[37]

Type A

Al	9–13%		
Ni	24–30%		
Co	5–10%		
Br	10,500–7,500	Hc	150–660

Type B

Ti	8–25%		
Ni	10–25%		
Co	15–30%		
Br	7,600–6,300	Hc	780–920

These values may be compared with those of tungsten steel

Br 10,000 and Hc 65 yielding $Br \times Hc = 650{,}000$, and with the expensive 35–41 per cent Co steel which yields

Br 9,700 and Hc 235 yielding $Br \times Hc = 2{,}280{,}000$.

Alnico with a nominal chemical composition of[36]

Al	12%
Ni	20%
Co	5%
Si	0.15%
Mn	0.15%
C	0.10%

is available with the following (minimum) values:

Br. (min.) 7,100 gauss Hc 400 oersteds, yielding $Br \times Hc = 2{,}840{,}000$.

However, considerably higher values of $Br \times Hc$ have been obtained with this type of alloy. It may be remarked that, as Scott has demonstrated, the product $Br \times Hc$ affords as good a criterion of the merit of a permanent magnet as does $(B_d H_d)$ max. and is more readily determined.

Chemical Properties

1. Oxidation and Corrosion

Nickel does not oxidize appreciably in air until a temperature of 400 to 500 degrees centigrade is reached and even then the reaction is slow and the oxide is adherent and protective. Iron acts much differently and oxidizes at much lower temperatures, even at room temperature, and the rates of oxidation at elevated temperatures are 800 to 1000

times those of nickel as has been demonstrated by the pioneer research of Pilling and Bedworth[38] whose results are presented in Fig. 21.

These differences are but a reflection of the high affinity of iron for oxygen and the nonprotective nature of its oxide film.

2. Corrosion in Indoor Atmospheres

Iron oxide has a tendency to absorb water yielding variously hydrated products better known as rust. Vernon[39] has carefully investigated the oxidation and rusting of iron under carefully controlled

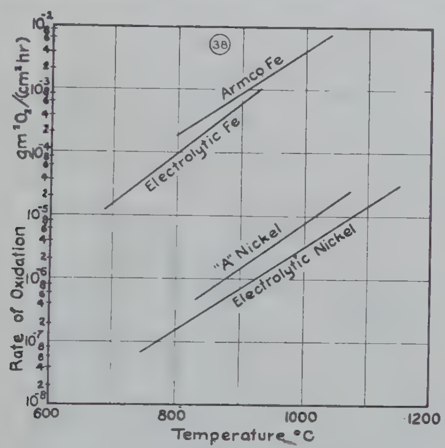


Fig. 21—Oxidation of nickel and iron.

atmospheric conditions. He employed several different types of atmospheres; the No. 1 atmosphere was maintained at a minimum average temperature of 65 degrees Fahrenheit and 45 per cent relative humidity, very mild conditions, while the No. 2 atmosphere involved a minimum average temperature of 48 degrees Fahrenheit and a humidity of 80 per cent. His results are shown in Fig. 22. He gave no curves for nickel under these conditions of exposure presumably because the amount of corrosion was too small to measure. He states, however, that nickel remained perfectly bright in No. 1 atmosphere for several months and showed neither tarnish nor fogging. Apparently no work was done on nickel in the No. 2 atmosphere but it is known that nickel will remain bright for long periods of time in the usual indoor atmospheres, although as quantitatively determined by Vernon[40] a characteristic fogging will develop in sulphurous atmospheres if the relative humidity exceeds 70 per cent.

The rapid corrosion of iron in indoor atmospheres occasions much

trouble in tube manufacturing operations not only because of the iron oxide formed but particularly because of the large amounts of water adsorbed or combined with this oxide which is thus carried into the tube. Furthermore, the rate of oxidation and rusting is variable and is the source of disturbing variations. It is also well recognized that traces of SO_2 accelerate the corrosion of metals and this gas is always present in industrial atmospheres, particularly in tube plants because of the numerous gas fires.

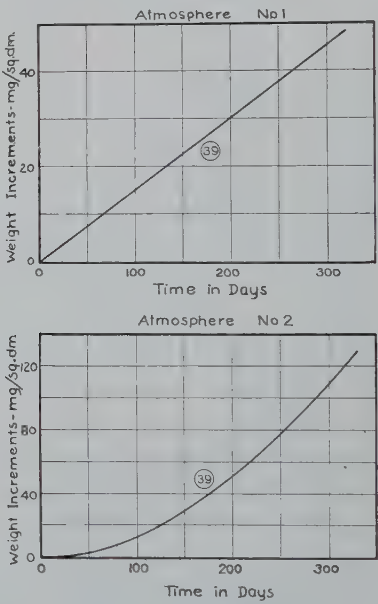


Fig. 22—Corrosion of Iron.

3. Corrosion Due to Chlorinated Degreasing Solvents.

A variety of solvents are used in the tube industry but to minimize fire hazard chlorinated organic compounds are generally employed. Moisture which is generally present causes some hydrolysis of these compounds producing hydrochloric acid which is decidedly corrosive. Moist carbon tetrachloride has been studied in detail and the corrosive effects on iron and nickel have been studied by several investigators and typical results are presented in Table IV.

Gas in Radio Metals

Gas is the least desirable impurity in a metal for vacuum tube service and every effort should be made to select a metal which can be relied on to be low in both surface and volume gas and which promptly

TABLE IV

Corrosion by Carbon Tetrachloride and Water at Room Temperature[41]

Metal	Loss in Weight Mg/Sq. Dm./24 hrs.	Remarks
Low C Steel	6.640	Marked corrosion and slight pitting, metal covered with heavy deposit of $Fe_2O_3+Fe_3O_4$
Nickel	0.028	No corrosion, very faint blue or yellow spots on surface of bright metal

yields its small content of gas during bombarding. In particular, the metal must be free from any tendency to "aftergas"; i.e., to dribble out slowly additional quantities of gas during the life of the tube. Gas of any kind alters the tube characteristics, but the electronegative elements such as phosphorus, sulphur, and probably nitrogen and gases containing oxygen, notably CO and H_2O are especially detrimental due to their effect upon the life and activity of the cathode.

Currently manufactured radio tubes contain a getter whose function is to perfect the vacuum beyond that produced by the exhaust pump, but no getter should be called upon to absorb substantial quantities of gas nor be burdened with appreciable quantities of gas evolved subsequent to the manufacture of the tube. As a matter of fact, a considerable number of long-life tubes, containing only nickel parts, have been made which contained no getter at all.

All metal contains some gas but the amount and composition of the gas and the ease with which it is removed during exhaust depends upon the affinity of the several gases for the particular metals present, upon the rate at which the gas diffuses through the metal, upon the methods employed in melting, and upon the methods employed in annealing during processing.

Some of the gas is located on or very near the surface of the metal in quantities dependent upon the surface condition and upon the amount of organic contamination present resulting from handling, etc. In the case of nickel, this surface gas is readily removed by brief hydrogen firing and parts so treated will not rust or oxidize on standing. If a rusty metal be employed, large amounts of oxygen, and particularly water vapor, will be carried into the tube, while if the metal is easily corroded by chlorinated solvents troublesome chlorides may also be introduced with very detrimental results. Likewise, oxidized surfaces are apt to acquire sufficient carbon from the underlying metal or from accidental contamination to cause subsequent reduction of the oxide during bombardment or subsequent use at elevated temperatures, yielding CO.

The remainder of the gas is distributed through the body of the

metal and is much more difficult to remove. A portion of it is in true solution. The remainder is combined with the basic metal, or with minor elements in the form of inclusions from which it may be slowly liberated on heating and diffuse in atomic form to the surface of the metal where it may remain adsorbed, combine to molecular form, or react with other elements such as carbon and then be removed. It is evident from the foregoing that the absence of actual blisters is absolutely no indication of the absence of gas.

The mechanism of outgassing, particularly of tungsten, molybdenum, and graphite, has been studied by Marshall and Norton[42] while a general survey has been made by Ransley and Smithells[43] which summarizes existing data on diffusion and presents the results of their own recent experiments.

The amount of residual gas in a metal after a definite bombarding cycle is related to the amount present initially, and upon the gases and metal employed. Therefore a low initial gas content is highly desirable. The stability of the gas-metal or metalloid compounds generally decreases with increased temperature, while the rates of diffusion of the elemental gases increase with the temperature; for these reasons the metal parts of vacuum tubes are heated to as high a temperature as other conditions permit to aid in the removal of as large a proportion of the gas as possible during the bombardment cycle. The importance of being able to use high temperatures in bombardment is indicated by the observation of Smithells and Ransley[43] that the rate of removal of small amounts of oxygen from nickel is almost four times as fast at 1050 degrees centigrade as at 950 degrees centigrade. It is also obvious that the bombarding temperature should be substantially higher than the operating temperature of the tube elements to avoid aftergassing.

Due to the use of hydrogen anneals, hydrogen is initially present in small quantities in most of the commercial metals but is so feebly held and diffuses so readily through nickel that its removal from this metal is prompt. The presence of any hydrogen in the finished tube will cause trouble if oxidized parts are present due to its tendency to reduce the oxide forming water vapor which is extremely detrimental to the tube.

Oxygen is most important, not only because it is frequently present in larger quantities and is more difficult to remove, but particularly because of its baleful effect upon cathode life. The amount of oxygen in commercial material is but a small fraction of the maximum amount soluble in the molten metal and depends markedly upon the affinity of oxygen for the particular metal employed. The amounts initially present are seldom determined by the solubilities, which are high (for instance, about 0.95 per cent FeO will dissolve in iron at the melting

point), but primarily by the affinity of the particular metal for oxygen. Oxygen possesses a strong affinity for iron but a much lower affinity for nickel—inherent characteristics which largely determine the relative oxygen contents of commercial forms of these two metals which are in the ratio of 10 to 50 or more to 1. Nickel is melted by special methods which insure a minimum oxygen content and finally an addition of about 0.1 per cent of magnesium is made which may further lower the available oxygen and confers several other desirable properties on the nickel. The methods employed in annealing nickel are such as to reduce the oxygen content further.

The estimation of the oxygen content of a metal may be accomplished either by highly heating samples of the material for a considerable time in a high vacuum, pumping off the evolved gas, and analyzing it by delicate volumetric methods or by heating the samples for a sufficient time in carefully purified hydrogen and determining the oxygen (which combines with the hydrogen to form H_2O) in the effluent gas.

The latter method has been highly developed and values determined by this means for various irons[44] and data for several heats of commercial "A" nickel obtained by the same method are noted below.

TABLE V

	Per cent 0	Cu. mm./gm. N.T.P. Equivalent Oxygen as CO
Ingot iron (low carbon, high purity)	0.040–0.060	560–840
Electrolytic Iron	0.018–0.024	250–340
Pure iron vacuum melted	0.003–0.006	42– 84
Ingot iron treated 16–20 hours in hydrogen at 1500°C.	0.002	28
Low and medium carbon milled steel	0.012–0.033	168–462
Commercial "A" nickel—sample A	0.001	14
B	0.002	28
C	0.001	14
D	0.002	28

It will be noted that the oxygen contents of both high purity iron and low and medium carbon steels are some thirty times those of the commercial "A" nickels, and that the oxygen content of iron, after drastic and commercially impractical purification by heating in hydrogen for 16 to 20 hours at 1500 degrees centigrade, is as high as or higher than that of regular "A" nickel.

Other studies made by radio tube manufacturers both in this country and abroad confirm these data. In their experiments samples of an iron offered for radio use* were heated to a high temperature in

* A typical lot analyzed:

Sulphur	0.023 per cent
Carbon	0.04
Phosphorus	0.005
Copper, Silicon, Manganese	Trace

vacuo and the extracted gases were quantitatively analyzed. These experiments also furnish additional information concerning the other gases evolved from iron. Their results are summarized below.

		Gas Cu. mm./gm. N. T. P.
Experiment A—Iron[52]		230
Experiment B—Iron cleansed by firing in hydrogen for 15 min. at 950°C	Sample 1[45]	92
	Sample 2[45]	103

In the first experiment about two thirds of the gas was CO, the remainder being largely nitrogen which came off slowly and was the principal gas evolved at the maximum temperature. In the second series the CO and nitrogen were measured together and comprised 93 to 96 per cent of the total gas. The remainder was probably hydrogen. These extremely large gas contents suggest that iron can hardly be called a gas-free metal,—indeed a leading authority on the subject of gas in radio metals stated that of the many metals which had been offered for radio purposes, this iron was by far the gassiest metal which he had thus far examined.

Nitrogen shows a strong affinity for iron, combining readily with it, forming moderately unstable nitrides, but has no affinity for nickel. Nitrogen is difficult to remove from iron so that it is the last gas to be evolved, being even more difficult to remove than oxygen. The nitrogen content of an iron offered for radio use has been found to be as high as 60 cubic millimeters normal temperature and pressure per gram which is perhaps twice as high as that normally found in iron and steel. Not only is the amount of nitrogen in iron very large but, as has been noted, it is difficult to remove it completely in any reasonable time and temperature.

The following data on nickel may be cited for comparison with the above results:

	Gas mm^3/gm N.T.P.
Vacuum melted nickel[42]	2.78
Electro nickel[42]	19.3
Drawn nickel wire (0.039″ diam.) cleaned by firing in hydrogen 15 min. at 950°C[43]	12.6

Probably 10 per cent of this gas is the easily removed hydrogen, the remainder largely CO.

These data are summarized in Fig. 23.

Smithells and Ransley,[43] in a recent investigation of the mechanism of the outgassing, find that while oxygen can diffuse through hot nickel it will remain adsorbed on the surface unless a reducing agent, normally carbon, be present. Only a minute amount of the latter is required to yield the small amounts of CO which are evolved on bom-

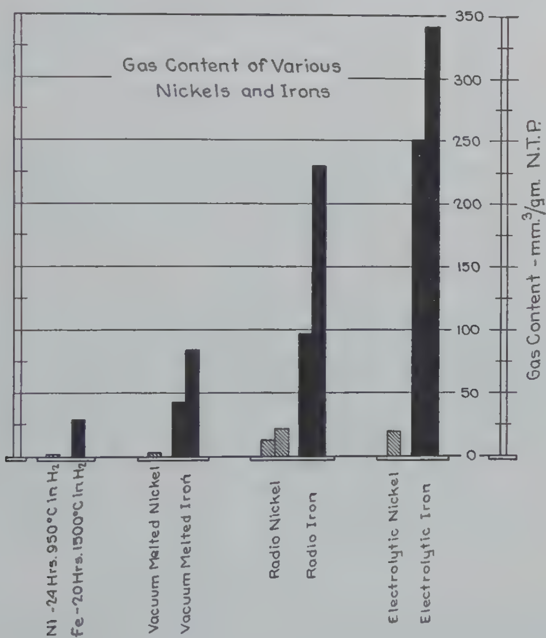


Fig. 23

bardment. The rate of removal of oxygen as CO is 3.6 times as rapid at 1050 degrees as at 950 degrees centigrade, which corresponds closely with the temperature coefficient of carbon diffusion but not with that for oxygen for which the ratio of diffusion rates (1050°C./950°C.) is 11.5. However, the actual rate of diffusion of oxygen, particularly at the lower temperatures is lower than that of carbon so that it is difficult to understand why the rate of diffusion of the latter is the limiting factor. However, it should be noted that in these diffusion experiments the hot nickel septum was saturated with carbon on one side and with oxygen on the other causing counter current diffusion which is quite dissimilar to that involved in normal outgassing and, as suggested by Paul D. Merica, may yield data which are not applicable

to the practical case which involves concurrent diffusion at low concentrations of both diffusing elements.

Phosphorus and sulphur while not gaseous at room temperature volatilize rather easily and in some respects behave like gases. The phosphorus content of nickel is very low, about 0.003 per cent, while that of iron may range from 0.018 to about 0.065 per cent. Phosphorus seems to be tolerated by thoriated cathodes but experiments indicate that it is detrimental to oxide-coated cathodes.

Sulphur in all tube parts is definitely detrimental and this element is carefully controlled in nickel, the amount present being normally 0.005 per cent or less. The sulphur content of irons is usually 0.025 to 0.45 per cent.[46] Some methods of steel manufacture lead to values as high as 0.060 per cent sulphur.

Sulphur is extremely detrimental to oxide-coated cathodes and the use of material containing appreciable quantities of this element in plates and other tube parts is known to be extremely undesirable.

Closure

The production of radio tubes is so complicated a process and the material requirements are so diverse that it is difficult to analyze the problem completely but we have endeavored to cover the more important aspects in the foregoing remarks with the hope that a broader understanding of the characteristics of nickel will aid the tube engineer to utilize fully the capabilities of the metal and thus reduce shrinkage and over-all costs to a minimum.

Acknowledgments

We have endeavored to give due credit for specific data cited but much general information has been contributed by tube engineers and by those engaged in rolling and drawing nickel for radio uses and is the fruit of their extensive experience. We wish to thank these gentlemen and particularly our associate, Mr. R. H. Shaefer for his assistance in the preparation of this paper and for tests which are constantly made to meet the increasingly diverse requirements of the electronic art.

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GROUND SYSTEMS AS A FACTOR IN ANTENNA EFFICIENCY*

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Summary—*Theoretical considerations concerning the losses in ground systems are advanced. These considerations indicate the feasibility of antennas much less than a quarter wave length tall, for low power broadcast use. The desirability of large ground systems is also indicated.*

Experimental data are given which show that an eighth-wave antenna is practically as efficient as a quarter-wave antenna. It is also found that a ground system consisting of 120 buried radial wires, each one-half wave long, is desirable. Tests of ground screens show them to be of no importance when adequate ground systems are used.

The experimental data include antenna resistance and reactance, field intensity at one mile, current in the buried wires, and total earth currents, for many combinations of antenna height, number of radial wires, and length of radial wires.

I. Introduction

IN THE past few years, many investigations have been made of the action of antennas whose heights have been of the order of a half wave length. The chief advantage of an antenna of this height is the antifading property, obtained when the antenna is of the proper shape. For a transmitter of low power, such an antenna is an unwarranted extravagance, since the service area of the station will generally be limited by signal deficiency or by interference from other stations, rather than by fading. For such a station, it has been the practice to use an antenna whose height is about one quarter of a wave length.

For some time, the authors have been of the opinion that much shorter antennas are feasible. This opinion was based on a number of theoretical considerations of antennas and ground systems. It is the purpose of this paper to discuss these considerations and to report on a series of experiments that were made to prove or disprove the validity of the theoretical results.

II. Theoretical Considerations

We shall concern ourselves entirely with straight vertical antennas, with a sinusoidal distribution of current on the antenna. The antenna is placed over a flat earth. The following notation will be used:

* Decimal classification: R326. Original manuscript received by the Institute, March 1, 1937. Presented before Silver Anniversary Convention, New York City, May 10, 1937.

a = antenna height
λ = operating wave length
G = angular antenna height $= 2\pi a/\lambda$ radians
$= 360 \cdot a/\lambda$ degrees (where a and λ are expressed in the same units).

Then
$$a/\lambda = G°/360.$$

Another useful relation is
$$a_{ft} = \lambda_m G°/110.$$

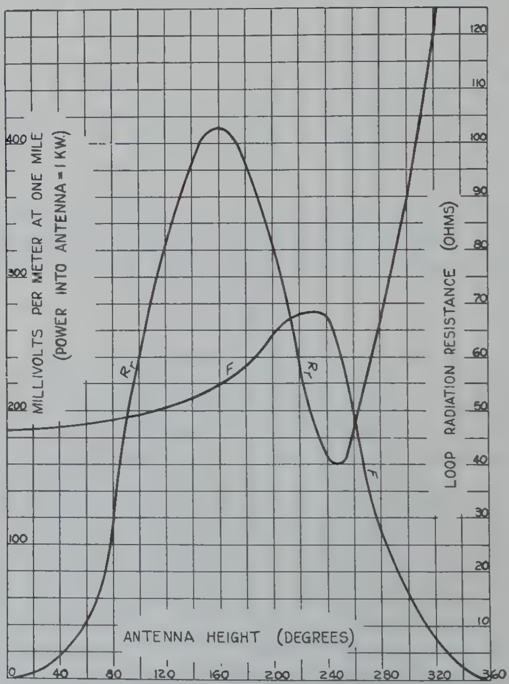


Fig. 1

The expression for the radiation resistance of such an antenna over a perfectly conducting earth is well known and has been published elsewhere.[1]

It is convenient to refer this resistance to the loop of antenna current. The radiation resistance referred to the loop current is given on Fig. 1 as a function of antenna height. The resistance at the base of the antenna is obtained from

$$R_r(\text{base}) = R_r(\text{loop})/\sin^2 G. \tag{1}$$

[1] G. H. Brown, "A critical study of the characteristics of broadcast antennas as affected by antenna current distribution," Proc. I.R.E., vol. 24, p. 52, equation (7); January, (1936).

Fig. 2 shows the radiation resistance referred to the antenna base for $0° < G \leqq 90°$. An approximate expression for this resistance, when G is less than 30 degrees is

$$R_r(\text{base}) \doteq 10 \cdot G^2 \tag{2}$$

where G is expressed in radians. Equation (2) is also plotted on Fig. 2.

The field strength at the surface of the earth, one mile from the antenna is[2]

$$F(\text{millivolts per meter}) = 37.25 I_0 \frac{1 - \cos G}{\sin G} \tag{3}$$

where I_0 is the current (amperes) at the base of the antenna.

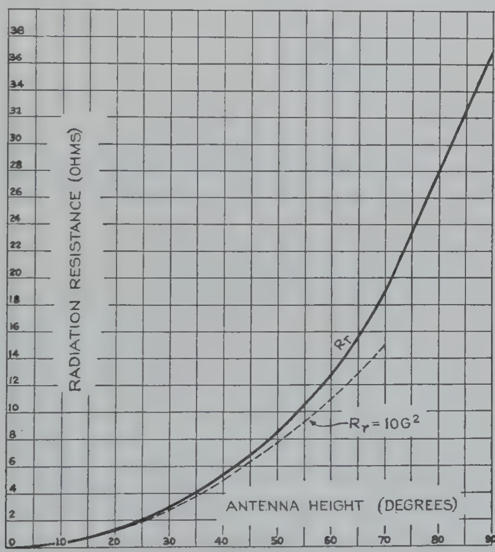


Fig. 2

For a constant radiated power, (3) becomes

$$F = 37.25 \sqrt{\frac{P}{R_r(\text{base})}} \cdot \frac{1 - \cos G}{\sin G} \tag{4}$$

where P is the power (watts) fed into the antenna.

Fig. 1 shows the field strength at one mile when the power is 1000 watts. We see that a quarter-wave antenna yields 194.5 millivolts per meter at one mile, while the best antifading antenna ($G = 190$ degrees) yields 245 millivolts per meter. This represents an increase of 27 per-

[2] H. E. Gihring and G. H. Brown, "General considerations of tower antennas for broadcast use," Proc. I.R.E., vol. 23, p. 345, equation (16); April, (1935).

cent over the quarter-wave antenna. This increase in field strength is insignificant compared to the importance of the antifading characteristic.

We see that as the antenna becomes shorter than a quarter wave length, the field strength remains practically constant. Let us consider the case where G is very small. Then the trigonometric terms may be represented by the series expansion

$$\sin G \doteq G$$
$$\cos G \doteq 1 - G^2/2$$
$$1 - \cos G \doteq G^2/2.$$

When these relations, together with (2) are substituted in (4), for a power of 1000 watts, the following result is obtained:

$$F = 37.25\sqrt{\frac{1000}{10G^2}} \cdot \frac{(0.5G^2)}{G} = 186.25 \text{ millivolts per meter.}$$

Thus an antenna of infinitesimal length, subject to no losses, yields a field strength which is only 4.25 per cent less than the field from a quarter-wave antenna.

While the preceding analysis demonstrates that the field of an infinitesimal antenna is practically equal to that of the quarter-wave antenna, the reader may find the following physical argument more satisfying. The distribution of field strength in a vertical plane around a quarter wave antenna is given by cos $(90° \cos \theta)]/\sin \theta$ while the distribution for an infinitesimal antenna is simply $\sin \theta$. The angle, θ, is measured from the zenith. A plot of these two equations is shown in Fig. 3. We see that the distribution patterns are very similar. Thus, with a given amount of radiated energy, and two distributions which are alike, the field strength at one mile must be the same in both cases.

Fig. 3

The considerations so far presented have been based on an antenna system free from losses, and a constant radiated power. In actual practice, we are interested in a constant power into the antenna. Then, with losses occurring in the system, the radiated power no longer remains constant. It is desirable to keep these losses as small as possible.

These losses are due to conduction of earth currents through a high resistance earth and to dielectric losses in the base insulator of the antenna. We shall next consider the earth currents flowing toward the antenna.

The earth currents are set up in the following manner. Displacement currents leave the antenna, flow through space, and finally flow into the earth where they become conduction currents. If the earth is homogeneous, the skin effect phenomena keep the current concentrated near the surface of the earth as it flows back to the antenna along radial lines. Where there are radial ground wires present, the earth current consists of two components, part of which flows in the earth itself and the remainder of which flows in the buried wires. As the current flows in toward the antenna, it is continually added to by more displacement currents flowing into the earth. It is not necessarily true that the earth currents will increase because of this additional displacement current, since all the various components differ in phase. Let us now suppose an imaginary cylinder sunk in the earth in such a fashion that the cylinder and the antenna are coaxial. The cylinder is of radius, x. Then we will denote the total earth current flowing radially inward across the surface of the cylinder as $\bar{I}_x$. If buried wires are present, $\bar{I}_x = \bar{I}_w + \bar{I}_e$, where $\bar{I}_w$ is the component flowing in the wires and $\bar{I}_e$ is the part which actually flows in the earth.

If the earth is perfectly conducting, the absolute value of the total earth current is

$$|I_x| = \frac{I_0}{\sin G}\sqrt{1 + \cos^2 G - 2\cos G \cos k(r_2 - x)} \tag{5}$$

where,

$$I_0 = \text{current at the base of the antenna}$$
$$r_2 = \sqrt{a^2 + x^2}$$
$$k = 2\pi/\lambda.$$

For a constant power,

$$|I_x| = \frac{1}{\sin G}\sqrt{\frac{P}{R_r}}\sqrt{1 + \cos^2 G - 2\cos G \cos k(r_2 - x)}. \tag{6}$$

When the distance, x, becomes large compared to the antenna height, r_2 becomes equal to x, and

$$|I_x| = \sqrt{\frac{P}{R_r}}\,\frac{1 - \cos G}{\sin G}. \tag{7}$$

Thus we see that the earth current at a distance is proportional to the field strength at one mile. Fig. 4 shows the total earth current for a number of antennas. The radiated power is 1000 watts. The antenna heights given here were chosen to conform to later experimental heights. We see that the earth currents at points more than 0.3 wave length from the antenna are practically the same for all antenna heights. Then the power lost in the earth beyond the 0.3-wave length radius will stay constant as the antenna height is changed, provided the radiated

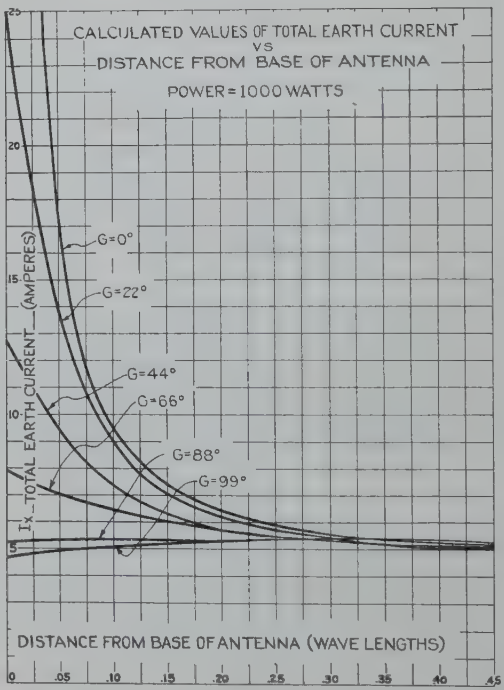


Fig. 4

power is maintained constant. Close to the antenna, the earth currents of a short antenna rise to large values. It would thus appear that the earth within the 0.3-wave length radius should be a very good conductor in order to operate a short antenna efficiently. This situation may be roughly approximated by a buried ground system consisting of many radial wires.

The actual earth current and the current flowing in the radial wires are given rather accurately by

$$\bar{I}_e/\bar{I}_w = j\gamma_e \cdot 4\pi^2 \cdot 10^{-9} f c^2 \left\{ \log \frac{c}{r} - 0.5 \right\} \tag{8}$$

where,

γ_e = earth conductivity (mhos per centimeter cube)
f = frequency (cycles per second)
x = distance from antenna (centimeters)
n = number of equally spaced radial wires
$c = \pi x/n$
r = radius of the wire in the ground system.

From (8) we see that the earth current proper leads the current in the wires by 90 electrical degrees.

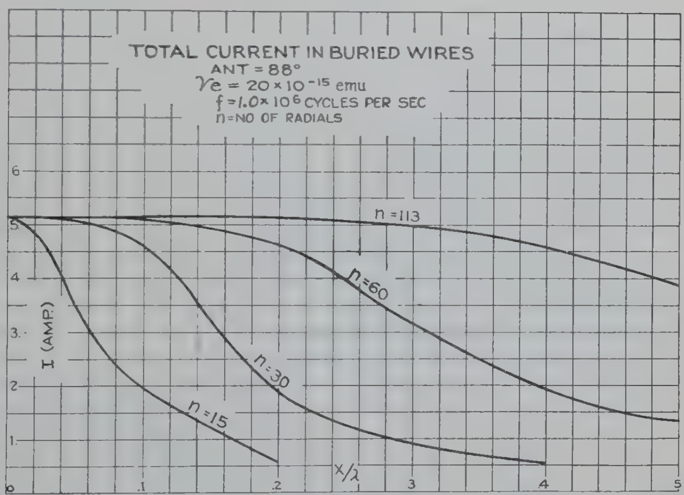


Fig. 5

The current in the wires is expressed in terms of the total earth current as

$$|\bar{I}_w/\bar{I}_x| = \left|\frac{1}{1 + \bar{I}_e/\bar{I}_w}\right| \tag{9}$$

while the current actually flowing in the earth is

$$|\bar{I}_e/\bar{I}_x| = \left|\frac{1}{1 + \bar{I}_w/\bar{I}_e}\right|. \tag{10}$$

Thus from (8), (9), and (10), together with Fig. 4, we may obtain the actual current in the earth and the current in the wires. It should be remembered that $\bar{I}_w$ is the current in a single wire multiplied by the number of wires.

Fig. 5 shows the current in the wires for the following conditions:

$G = 88°$
$\gamma_e = 0.2 \times 10^{-4}$ mhos per cm cube $= 20 \times 10^{-15}$ e.m.u.
$f = 1000$ kc.

Fig. 6 shows the actual current in the earth for the same conditions. These diagrams show that the ground system consisting of only 15 radial wires need not be more than 0.1 wave length long, while the system consisting of 113 radials is still effective out to 0.5 wave length.

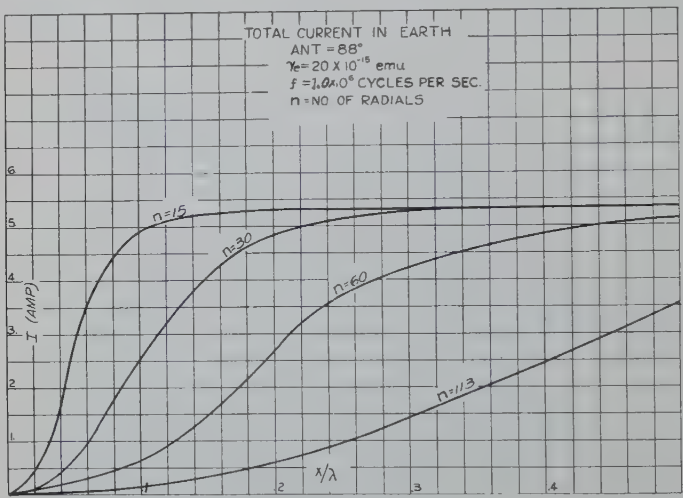


Fig. 6

Since later experimental work was carried out on a frequency of 3000 kilocycles, the following calculations are made on this basis. The current in the wires is shown for the following conditions:

Fig. 7 $\gamma_e = 0.2 \times 10^{-4}$ mhos per cm cube $= 20 \times 10^{-15}$ e.m.u. $G = 88°$.
Fig. 8 $\gamma_e = 1.0 \times 10^{-4}$ mhos per cm cube $= 100 \times 10^{-15}$ e.m.u. $G = 88°$.
Fig. 9 $\gamma_e = 0.2 \times 10^{-4}$ mhos per cm cube $= 20 \times 10^{-15}$ e.m.u. $G = 22°$.
Fig. 10 $\gamma_e = 1.0 \times 10^{-4}$ mhos per cm cube $= 100 \times 10^{-15}$ e.m.u. $G = 22°$.

The actual earth current, $\bar{I}_e$, is shown for the same conditions by Figs. 11, 12, 13, and 14. In all cases the radiated power is 1000 watts. These figures show the importance of using a large number of radial wires, of great length. When the earth is of good conductivity, the current leaves the wires and enters the earth closer to the antenna than it does when the earth is a poor conductor. Thus the regions of high current density are subjected to still more current with higher losses in these regions. There seems to be a compensating effect which tends to make the system somewhat independent of earth conductivity, over a limited range.

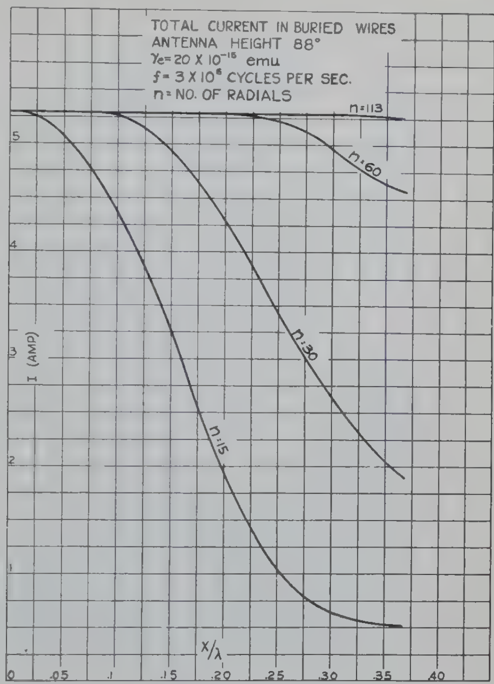

TOTAL CURRENT IN BURIED WIRES
ANTENNA HEIGHT 88°
γ_e = 20 X 10^{-15} emu
f = 3 X 10^6 CYCLES PER SEC.
n = NO. OF RADIALS
n=113
n=60
n=30
n=15
I (AMP)
x/λ
0
.05
.1
.15
.20
.25
.30
.35
.40
1
2
3
4
5

Fig. 7

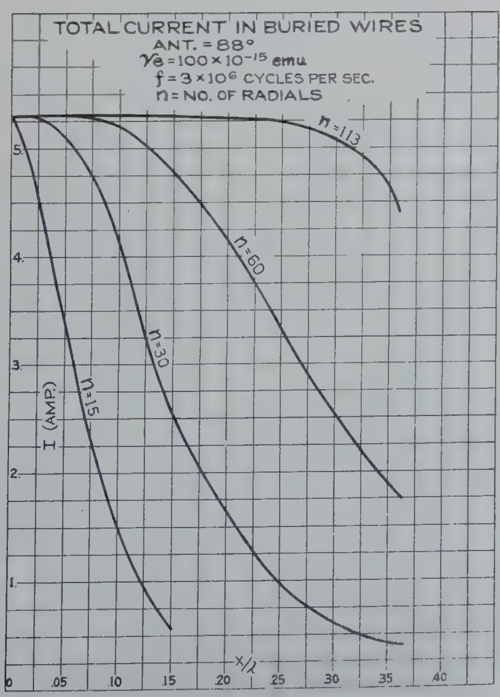

TOTAL CURRENT IN BURIED WIRES
ANT. = 88°
γ_e = 100 × 10^{-15} emu
f = 3 × 10^6 CYCLES PER SEC.
n = NO. OF RADIALS
n=113
n=60
n=30
n=15
I (AMP.)
x/λ
0
.05
.10
.15
.20
.25
.30
.35
.40
1.
2.
3.
4.
5.

Fig. 8

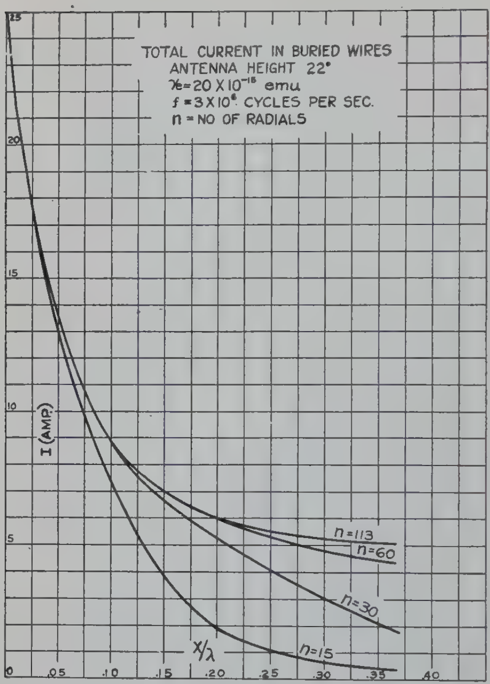

TOTAL CURRENT IN BURIED WIRES
ANTENNA HEIGHT 22°
$\gamma_e = 20 \times 10^{-15}$ emu
$f = 3 \times 10^6$ CYCLES PER SEC.
n = NO OF RADIALS
I (AMP)
X/λ
n=113
n=60
n=30
n=15
0
.05
.10
.15
.20
.25
.30
.35
.40
5
10
15
20
25

Fig. 9

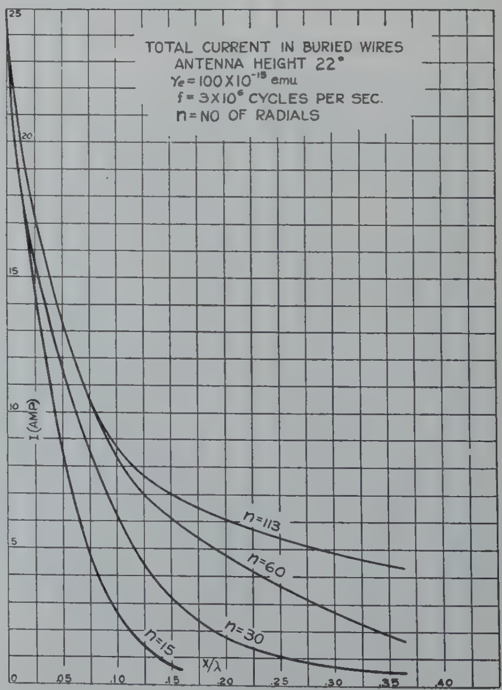

TOTAL CURRENT IN BURIED WIRES
ANTENNA HEIGHT 22°
$\gamma_e = 100 \times 10^{-15}$ emu
$f = 3 \times 10^6$ CYCLES PER SEC.
n = NO OF RADIALS
I (AMP)
X/λ
n=113
n=60
n=30
n=15
0
.05
.10
.15
.20
.25
.30
.35
.40
5
10
15
20
25

Fig. 10

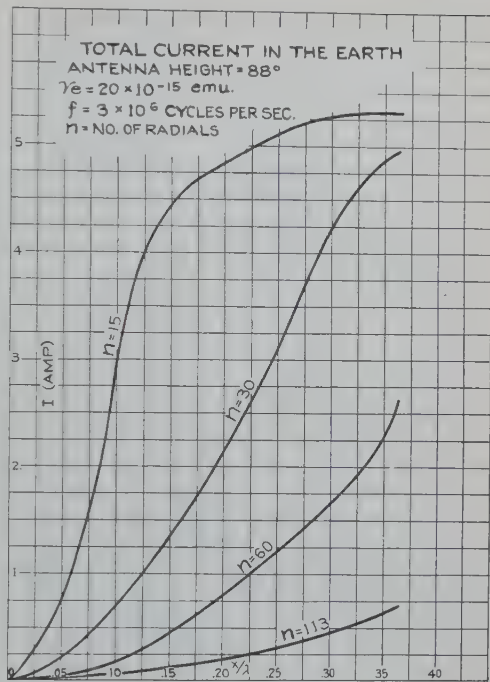

TOTAL CURRENT IN THE EARTH
ANTENNA HEIGHT = 88°
$\gamma_e = 20 \times 10^{-15}$ emu.
$f = 3 \times 10^6$ CYCLES PER SEC.
n = NO. OF RADIALS
I (AMP)
n=15
n=30
n=60
n=113
x/λ
0
.05
.10
.15
.20
.25
.30
.35
.40
1
2
3
4
5

Fig. 11

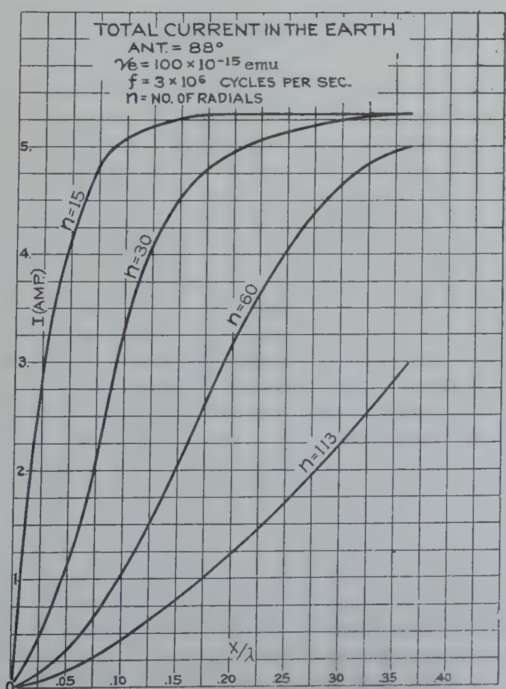

TOTAL CURRENT IN THE EARTH
ANT. = 88°
$\gamma_e = 100 \times 10^{-15}$ emu
$f = 3 \times 10^6$ CYCLES PER SEC.
n = NO. OF RADIALS
I (AMP.)
n=15
n=30
n=60
n=113
x/λ
0
.05
.10
.15
.20
.25
.30
.35
.40
1
2
3.
4.
5.

Fig. 12

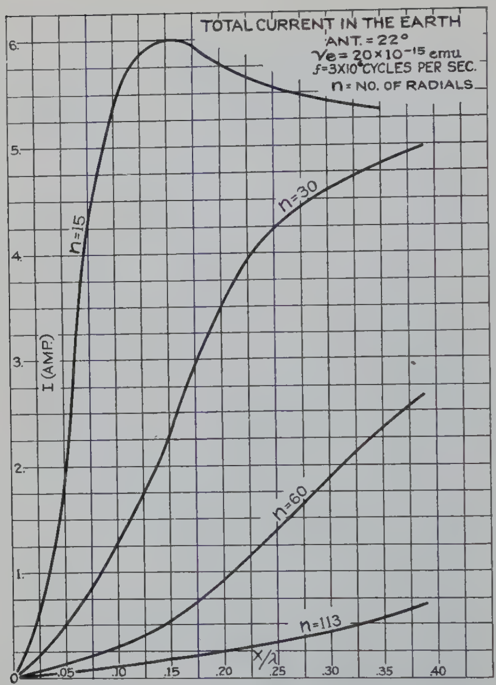

TOTAL CURRENT IN THE EARTH
ANT. = 22°
$\gamma e = 20 \times 10^{-15}$ emu
$f = 3 \times 10^6$ CYCLES PER SEC.
n = NO. OF RADIALS
I (AMP.)
n=15
n=30
n=60
n=113
X/λ
0
.05
.10
.15
.20
.25
.30
.35
.40
1.
2.
3.
4.
5.
6.

Fig. 13

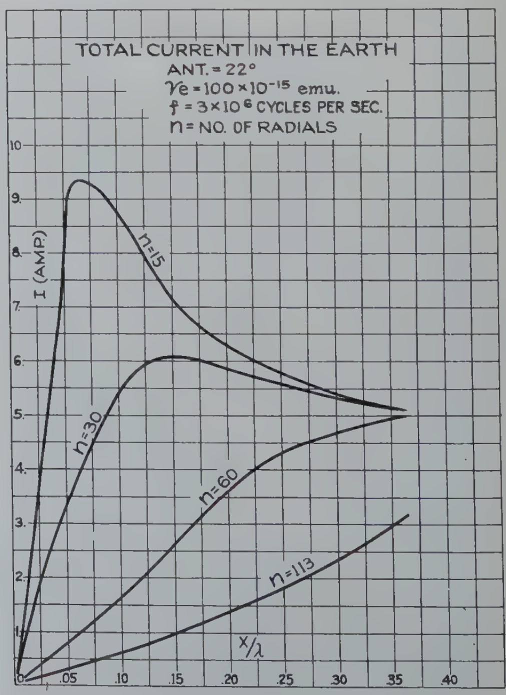

TOTAL CURRENT IN THE EARTH
ANT. = 22°
$\gamma e = 100 \times 10^{-15}$ emu.
$f = 3 \times 10^6$ CYCLES PER SEC.
n = NO. OF RADIALS
I (AMP.)
n=15
n=30
n=60
n=113
X/λ
0
.05
.10
.15
.20
.25
.30
.35
.40
1.
2.
3.
4.
5.
6.
7.
8.
9.
10

Fig. 14

From (8), we see that the distribution of currents depends on the wire size in a logarithmic fashion. Thus quite a variation in wire size

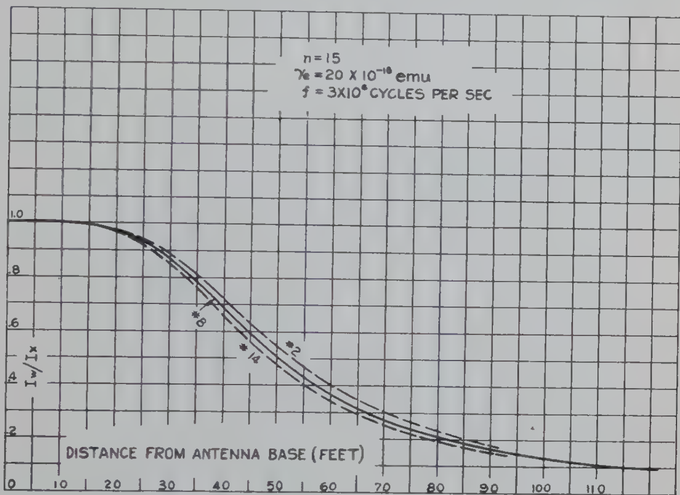


Fig. 15

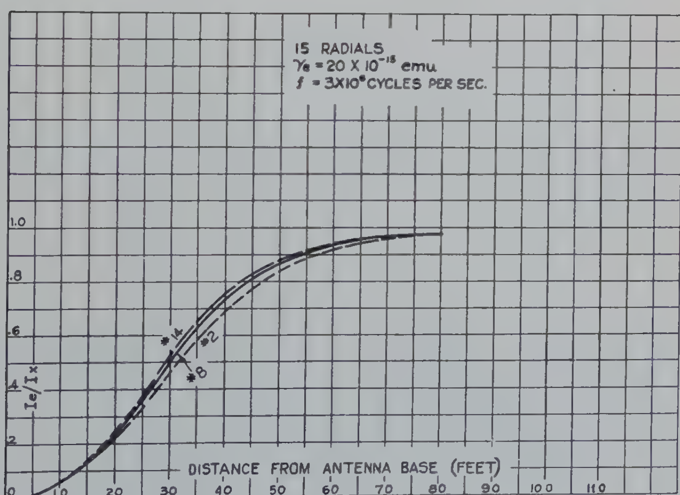


Fig. 16

may be tolerated. Fig. 15 shows the current in the buried wires for three wire sizes, No. 2, No. 8, and No. 14. Fig. 16 shows the actual earth current for these three wire sizes.

Let us now examine Fig. 17. The current is flowing toward the antenna through a ring of earth of radius, x, width, dx, and depth, s, where s is the skin thickness of the earth, given by

$$s = \frac{1}{\sqrt{\pi \mu \gamma_e f}} \text{ (cm)}$$

$\mu = 4\pi \cdot 10^{-9}$
γ_e = conductivity of earth (mhos per cm³)
f = frequency (cycles per second).

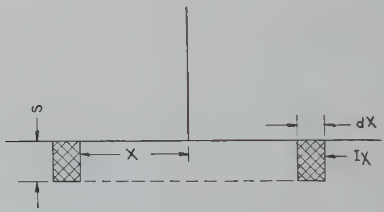


Fig. 17

Then if no wires are present in the earth, the power lost in a ring of width, dx, is

$$dP = \frac{I_x^2 dx}{2\pi x s \gamma_e}. \tag{11}$$

When wires are present, the current will not be distributed the same. We shall assume that the change in distribution is slight, but the current in the earth will now be given by I_ϵ, so that the watts lost per centimeter are

$$\frac{dP}{dx} = \frac{I_\epsilon^2}{2\pi x s \gamma_e}. \tag{12}$$

If the distance, x, is measured in meters, the power loss will be given in watts per meter. Fig. 18 shows the distribution of earth loss for $G=22$ degrees, and $G=88$ degrees, for 15 and 113 radial wires, when the frequency was 3000 kilocycles and the earth conductivity is 0.2×10^{-4} mhos per cm². The area under each curve represents the power lost in the earth. We see that the power lost in a ground system consisting of 113 wires, each 0.4 wave length long, is insignificant. With 15 wires and $G=88$ degrees, and a radiated power of 1000 watts, the power lost in the ground system out to 0.4 wave length is 447. watts, while the power lost for a 22-degree antenna is 745. watts.

III. Experimental Procedure and Apparatus

In the past, experimental curves similar to the theoretical field intensity curve shown in Fig. 1 have been made by maintaining a fixed antenna height and varying the frequency over a wide range. These curves have generally been flat in the vicinity of quarter-wave antenna heights. However, such results have been questionable, because of the fact that the ground system becomes a different fraction

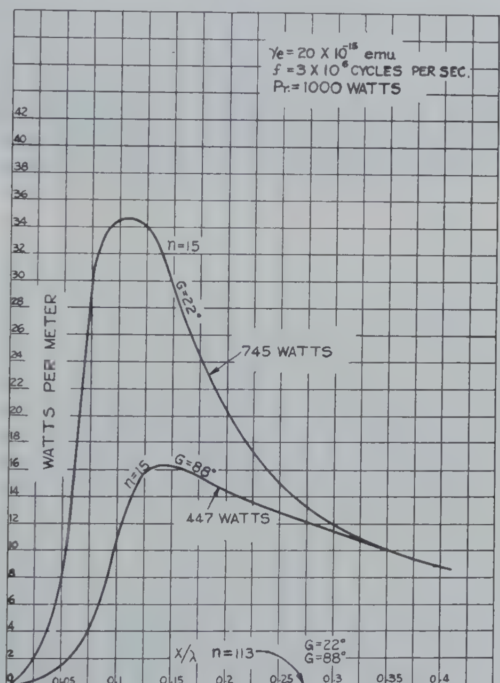


Fig. 18

of a wave length long each time the frequency is changed, while at the low frequencies, the attenuation in the first mile is less than for the high frequencies. Thus, in planning the experiments about to be described, it was decided that the frequency must remain fixed, while the antenna height itself was adjusted. The frequency of operation was 3000 kilocycles. The following combinations were tested:

1. The radial wires were made 0.411, 0.274, and 0.137 wave length long, (135, 90, and 45 feet, respectively).

2. For each length of radial system, 2, 15, 30, 60, and 113 radial wires were used.

Fig. 19

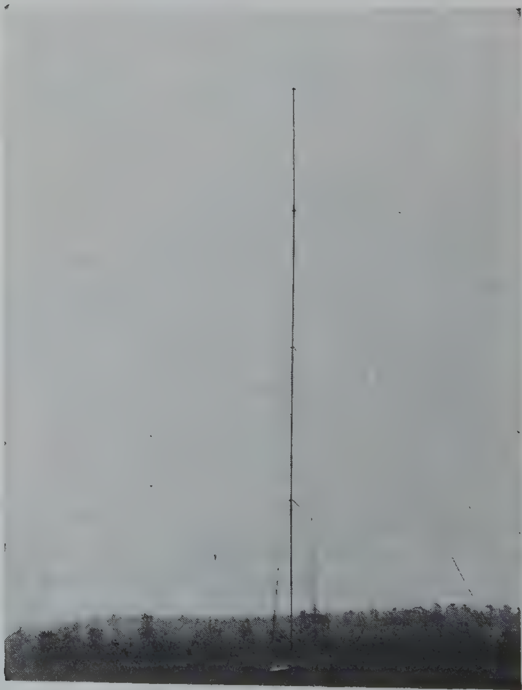


Fig. 20

3. For each combination of ground wire length and number of wires, the antenna heights were $G=22$, 44, 66, 88, and 99 degrees, with intermediate heights where necessary.

Since the above procedure involved the laying of many miles of wire, the plow shown in Fig. 19 was constructed and used throughout the experiments. The blade cut a narrow furrow, laid a soft No. 8 copper wire in the groove, and partially filled the groove. The wire was thus buried at a depth of approxyimatelix in sches.

Fig. 21

Fig. 22

The antenna consisted of a galvanized iron mast, 2.5 inches in diameter. The mast consisted of four sections, each 20 feet in length, topped by a single section, 10 feet in length. Thus the height could be any multiple of 10 feet, up to 90 feet. The complete mast is shown by Fig. 20. The mast was raised and lowered for adjustment by the arrangement shown in Fig. 21.

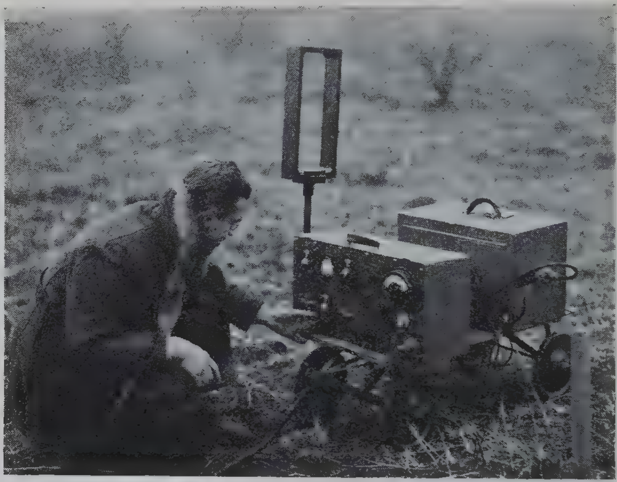


Fig. 23

Fig. 24

The base of the mast rested on a hardwood insulator. This may be seen at the left of Fig. 22. The oscillator and measuring equipment may be seen in this same figure. The resistance of the antenna was measured

by the resistance substitution method. Then the variation of the antenna tuning condenser determined the antenna reactance.

The total earth current as a function of distance from the antenna was measured by a method described elsewhere.[2] A conventional field intensity measuring set was used for this purpose. (Fig. 23.)

For each antenna height, 0.2 watt of power was fed into the antenna and the field intensity was measured at 0.3 of a mile. This figure was then converted to a basis of a power of 1000 watts and a distance of one mile.

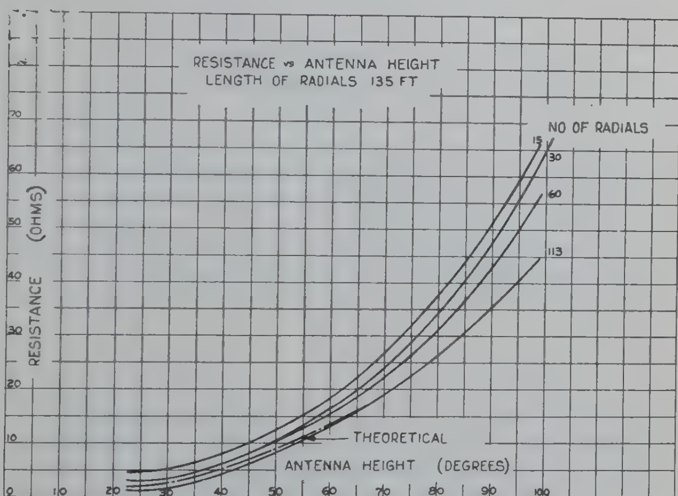


Fig. 25

The current in the buried wires was measured in each case. This was accomplished by placing a coil next to the ground wire at a point where the wire was exposed. The coil was resonated by means of a small shunt condenser. The voltage across this combination was determined with a vacuum tube voltmeter. The combination was calibrated in the laboratory. Fig. 24 shows the procedure in question. This measurement yielded the current in a single wire. To obtain the current flowing in all the buried wires at distance, x, the measured value was multiplied by the number of wires.

IV. Experimental Data

The first ground system installed consisted of 113 radials, each 135 feet long. The wires were then reduced in number. Fig. 25 shows

[2] *Loc. cit.*, p. 336.

the measured antenna resistance as a function of antenna height, for the various number of wires used. We see that the resistance is lowered steadily as the number of wires is increased.

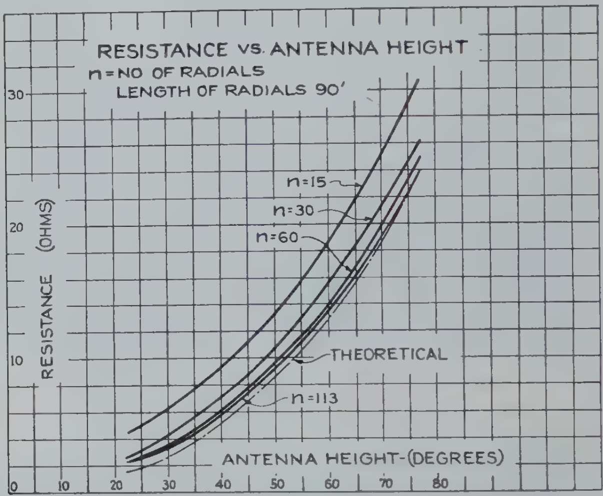


Fig. 26

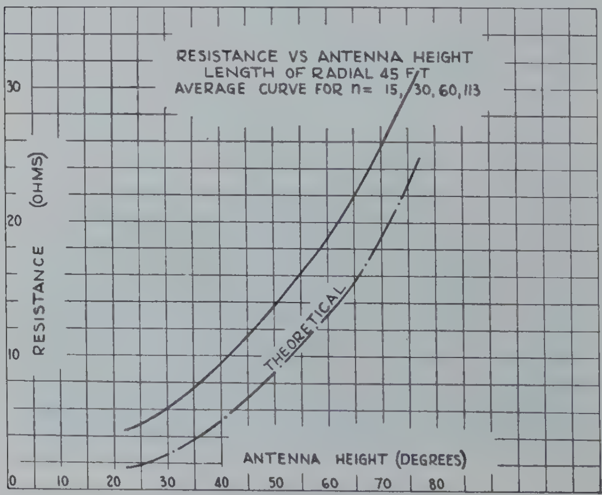


Fig. 27

Fig. 26 shows the resistance curves when the ground system was 90 feet in radius. The resistance of this system is slightly higher than that of the system 135 feet in radius, when 113 wires are used. However

when only 15 wires are used, the resistance does not change when the wires are shortened. This is due to the fact that very little of the total

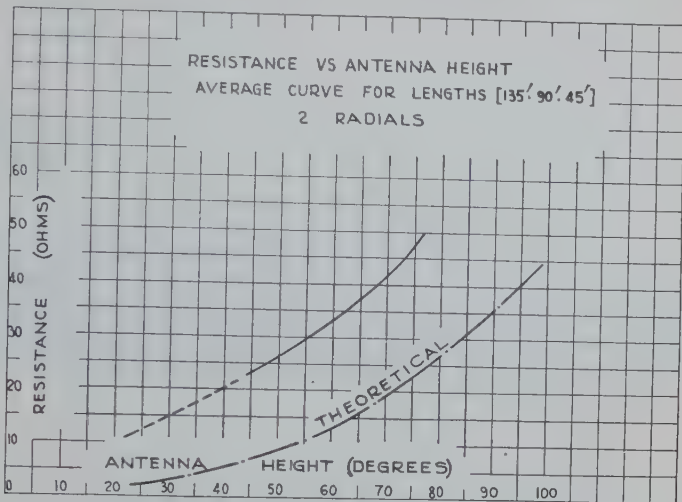


Fig. 28

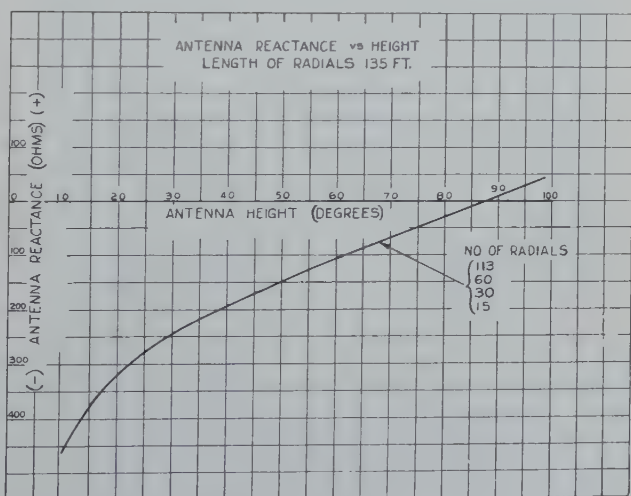


Fig. 29

earth current is flowing in the wires at distances greater than 90 feet, when only 15 wires are used.

When the radial wires were 45 feet long, the measured resistance was practically independent of the number of wires. Evidently, most

of the earth loss occurred in regions beyond the periphery of the ground system. Fig. 27 is an average curve obtained for this condition.

When only two radial wires, separated 180 degrees, were used, the resistance was independent of wire length since the current vanished from the wires within a few feet of the antenna. The results of this test are shown in Fig. 28.

The reactance of the antenna was found to vary slightly with the ground system. For all practical purposes, the reactance may be re-

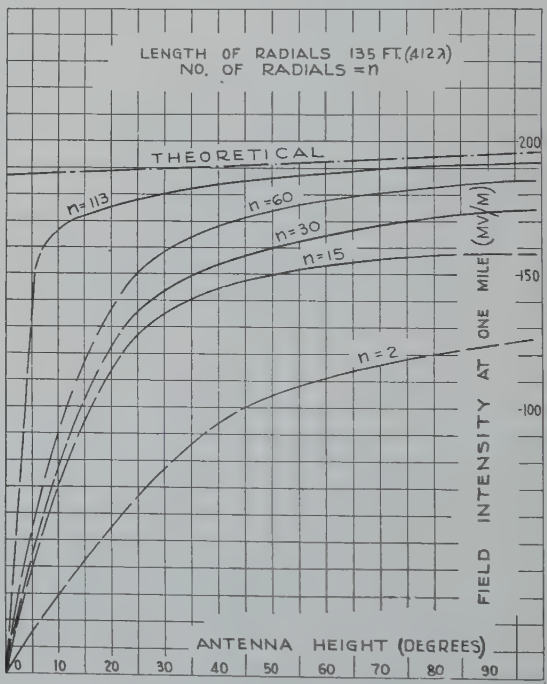


Fig. 30

garded as constant for a given antenna height. The antenna reactance as a function of antenna height is given by Fig. 29.

The field intensity at one mile for an antenna power of 1000 watts is given in Fig. 30, when the ground system was 135 feet in radius. It is seen that the ground system consisting of 113 radial wires is very nearly perfect. It was found that the antenna shown in Fig. 31 ($G=22$ degrees) gave a field strength only 8.5 per cent less than the antenna shown in Fig. 20 ($G=99$ degrees). Fig. 32 shows the field intensity when the ground system was 90 feet in radius. The results are somewhat inferior to those obtained with the larger ground system. In Fig. 33, we see that the field strength is nearly independent of the number of

Fig. 31

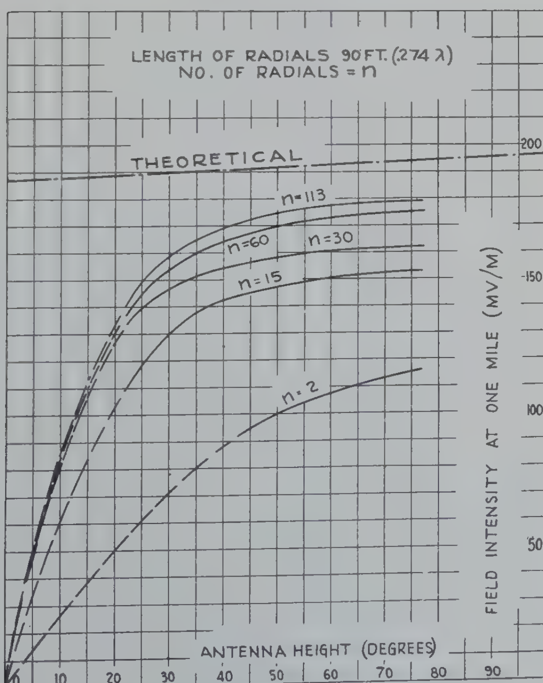


Fig. 32

wires for a ground system only 45 feet in radius, with the reservation that at least 15 wires are used. Two radial wires are much worse.

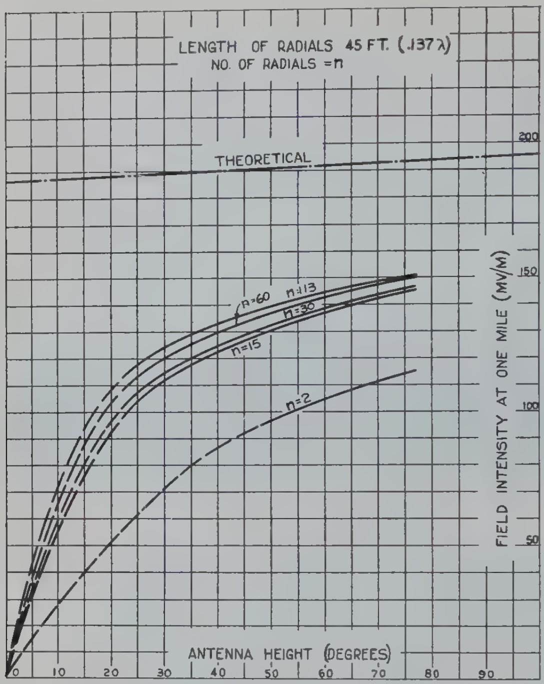

LENGTH OF RADIALS 45 FT. (.137λ)
NO. OF RADIALS = n
THEORETICAL
n=60
n=113
n=30
n=15
n=2
FIELD INTENSITY AT ONE MILE (MV/M)
200
150
100
50
ANTENNA HEIGHT (DEGREES)
0
10
20
30
40
50
60
70
80
90

Fig. 33

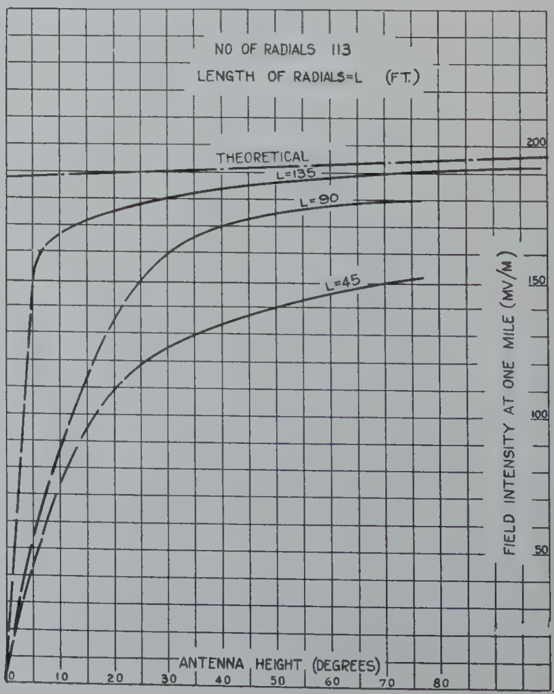

NO OF RADIALS 113
LENGTH OF RADIALS=L (FT.)
THEORETICAL
L=135
L=90
L=45
FIELD INTENSITY AT ONE MILE (MV/M)
200
150
100
50
ANTENNA HEIGHT (DEGREES)
0
10
20
30
40
50
60
70
80

Fig. 34

These data have been replotted in Fig. 34 in a slightly different manner. Here the number of radials is fixed at 113. The three curves of field intensity are for the three lengths of ground system tested. Fig. 35 shows similar curves when 15 radial wires are used. These two figures show the necessity of using many wires in an extended ground system. At the same time, if the ground system consists of only a few radial wires, there is no point in extending the wires to great lengths.

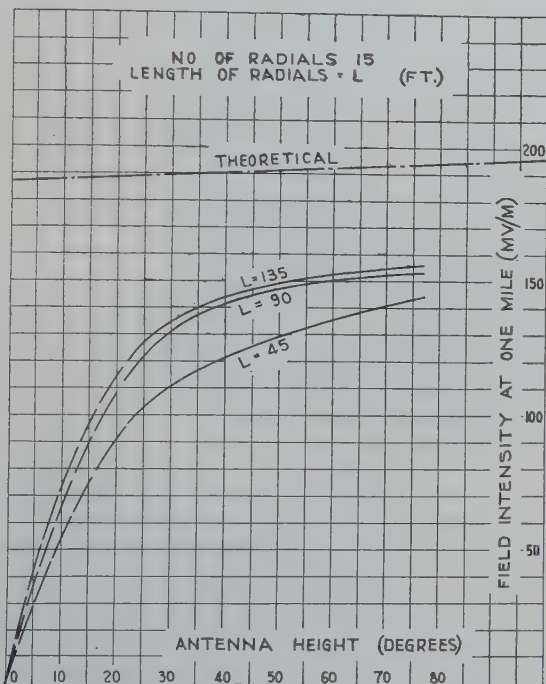


Fig. 35

Fig. 36 shows the dependence of field strength and resistance on the number of radials. The antenna height was fixed at 77 degrees and the radial length at 135 feet. When the length was changed to 45 feet, the results shown in Fig. 37 were obtained.

Field intensity and resistance as a function of ground wire length are illustrated in Fig. 38, when 113 radials were used. Fig. 39 shows the same type of curves for 15 radials. These diagrams again illustrate the fact that it is useless to extend a few radial wires, while some gain is realized if a great many wires are extended to great lengths.

The total earth currents were measured, using the apparatus shown in Fig. 23. It was found that the shape of the total earth current curve

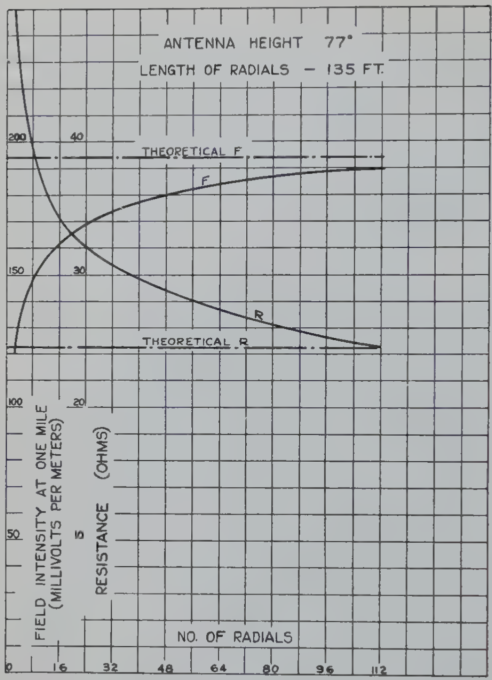

ANTENNA HEIGHT 77°
LENGTH OF RADIALS — 135 FT.
THEORETICAL F
F
R
THEORETICAL R
FIELD INTENSITY AT ONE MILE
(MILLIVOLTS PER METERS)
RESISTANCE (OHMS)
NO. OF RADIALS
200
40
150
30
100
20
50
10
0
16
32
48
64
80
96
112

Fig. 36

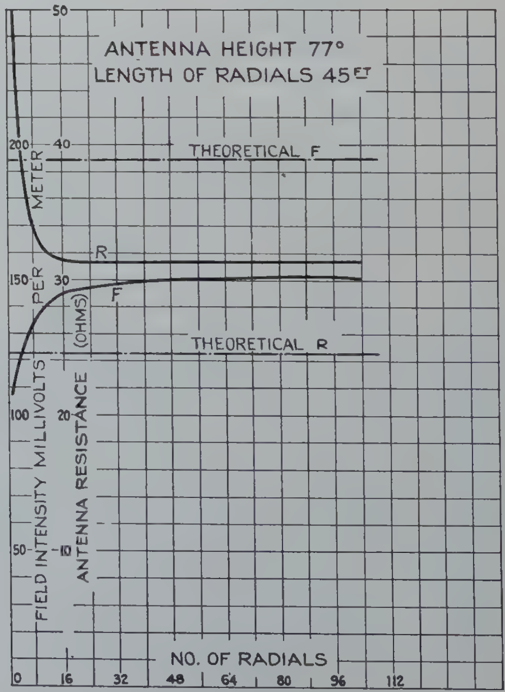
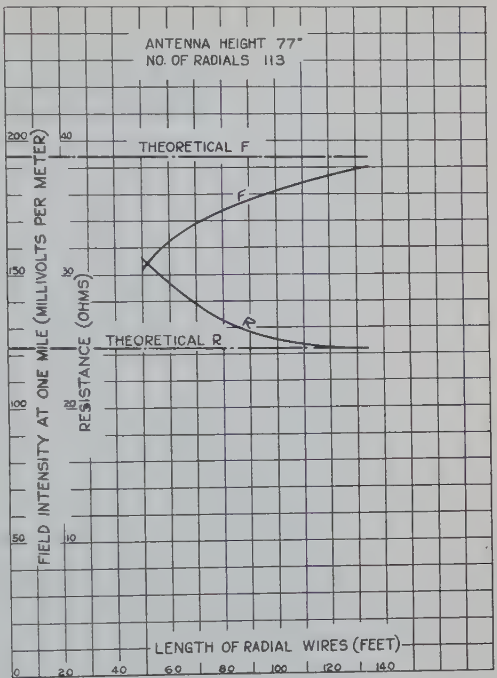
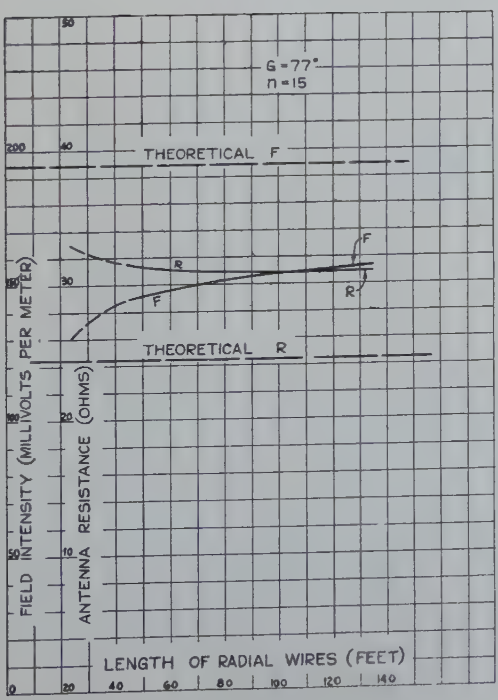

ANTENNA HEIGHT 77°
LENGTH OF RADIALS 45 FT
THEORETICAL F
R
F
THEORETICAL R
FIELD INTENSITY MILLIVOLTS PER METER
ANTENNA RESISTANCE (OHMS)
NO. OF RADIALS
50
200
40
150
30
100
20
50
10
0
16
32
48
64
80
96
112

Fig. 37



ANTENNA HEIGHT 77°
NO. OF RADIALS 113
THEORETICAL F
F
R
THEORETICAL R
FIELD INTENSITY AT ONE MILE (MILLIVOLTS PER METER)
RESISTANCE (OHMS)
200
150
100
50
40
30
20
10
LENGTH OF RADIAL WIRES (FEET)
0
20
40
60
80
100
120
140

Fig. 38



G = 77°
n = 15
THEORETICAL F
F
R
THEORETICAL R
FIELD INTENSITY (MILLIVOLTS PER METER)
ANTENNA RESISTANCE (OHMS)
200
150
100
50
50
40
30
20
10
LENGTH OF RADIAL WIRES (FEET)
0
20
40
60
80
100
120
140

Fig. 39

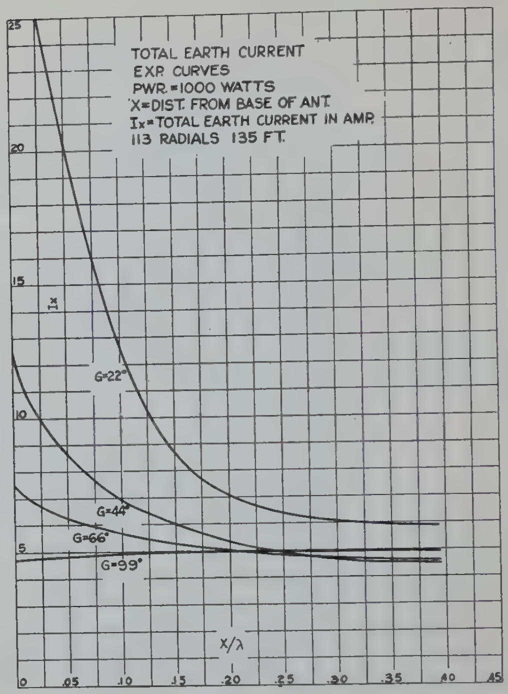

TOTAL EARTH CURRENT
EXP. CURVES
PWR.=1000 WATTS
X=DIST. FROM BASE OF ANT.
Ix=TOTAL EARTH CURRENT IN AMP.
113 RADIALS 135 FT.
Ix
G=22°
G=44°
G=66°
G=99°
X/λ
25
20
15
10
5
0
.05
.10
.15
.20
.25
.30
.35
.40
.45

Fig. 40

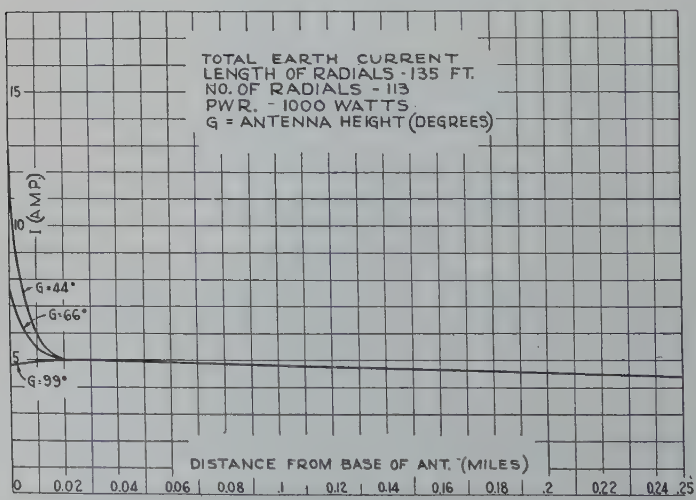

TOTAL EARTH CURRENT
LENGTH OF RADIALS - 135 FT.
NO. OF RADIALS - 113
PWR. - 1000 WATTS
G = ANTENNA HEIGHT (DEGREES)
I (AMP.)
G=44°
G=66°
G=99°
DISTANCE FROM BASE OF ANT. (MILES)
15
10
5
0
0.02
0.04
0.06
0.08
.1
0.12
0.14
0.16
0.18
.2
0.22
0.24
.25

Fig. 41

was practically independent of ground system for a fixed antenna height. However, the scale factor changed with antenna resistance, since the input power was held constant in all cases. Fig. 40 shows the measured earth currents out to a point which is 0.4 wave length from the antenna, for a number of antenna heights, when the ground system consisted of 113 radial wires, each 135 feet in length. Fig. 41 shows the same results plotted to a more extended scale. Here the distance from

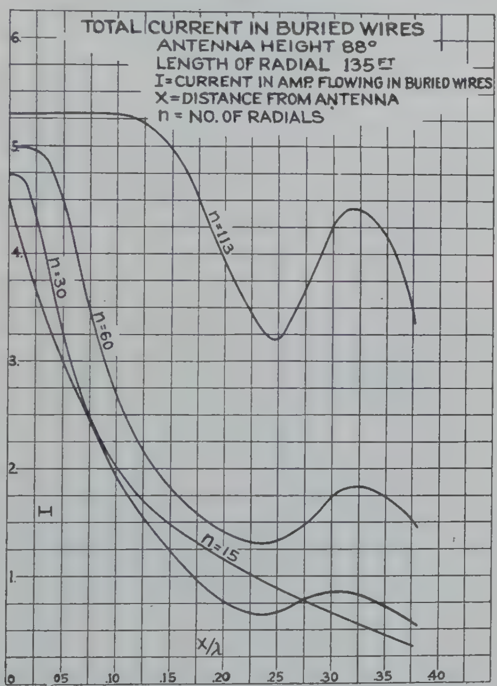


Fig. 42

the antenna is expressed in miles. The most remote point, 0.25 mile, is four wave lengths from the antenna.

For each ground system, the current in the buried wires was measured as shown in Fig. 24. The value measured in a single wire was then multiplied by the number of buried wires. The current in the buried wires for an antenna height of 88 degrees and radial wires 135 feet long is shown in Fig. 42. We see that the current persists in 113 wires much further from the antenna than it does for a smaller number of wires. Fig. 43 shows similar results for the same ground system and a 22-degree antenna.

A few tests were made of the action of an earth screen at the base of the antenna. In the first test, the ground system consisted of 113 radial wires, each 135 feet long. The ground screen consisted of a square copper screen, nine feet on a side. Absolutely no difference in field

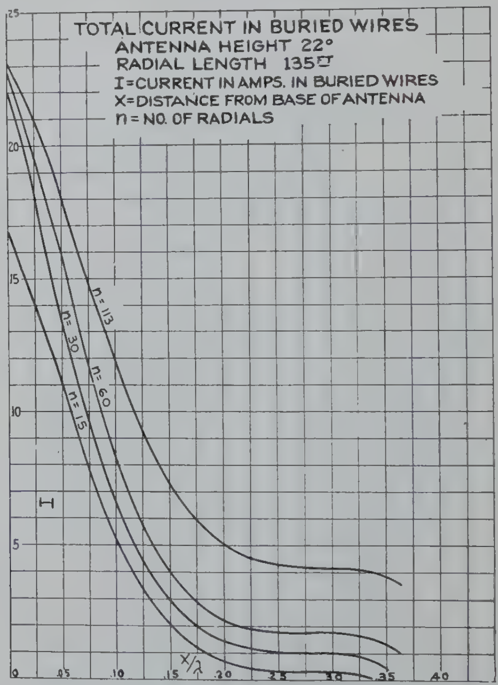


Fig. 43

strength or antenna resistance could be detected when the screen was removed and the buried ground system used alone.

	Resistance	Field Intensity
113 buried wires; no earth screen	1.0	1.0
15 buried wires; earth screen	1.62	0.785
15 buried wires; no earth screen	3.24	0.555

The second test was made using 15 buried radial wires and the earth screen. The relative results are shown above. Thus we see that, with a small ground system, the earth screen furnishes a definite improvement. However, the results obtained are not nearly as good as those obtained with the large ground system. Further, when the large ground system is used, the earth screen gave no further improvement.

Another set of measurements was made in which the ground system

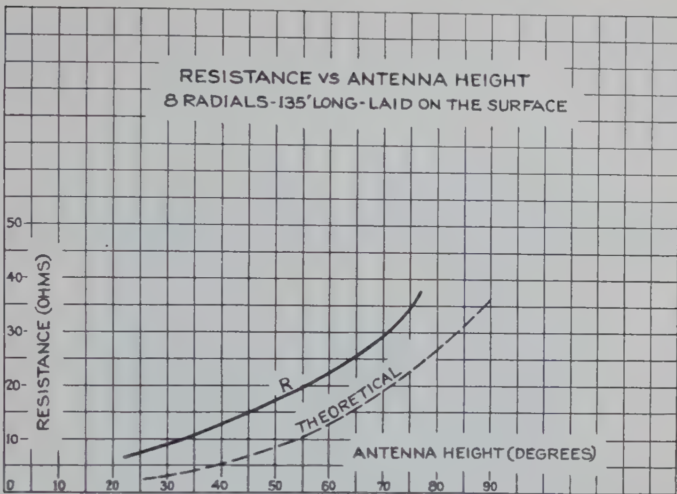


Fig. 44

consisted of eight radial wires, each 135 feet long. These wires were laid on the surface of the earth. The ends of the wires were terminated in ground rods. Fig. 44 shows the measured antenna resistance for this case, while Fig. 45 gives the measured field strength for the some con-

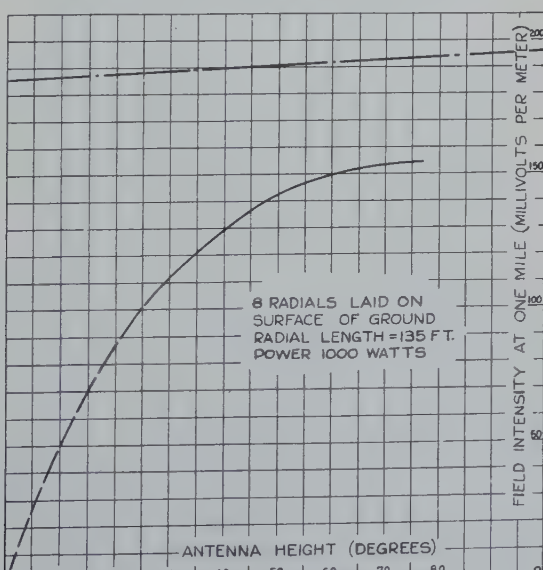


Fig. 45

ditions. We see that this ground system is about as good as an equal number of buried wires. These data are of interest since this is typical of the portable systems used for testing possible sites for broadcast transmitters.

V. Conclusion

These experiments show that, even with a poor ground system, an eighth-wave antenna performs practically as well as a quarter-wave

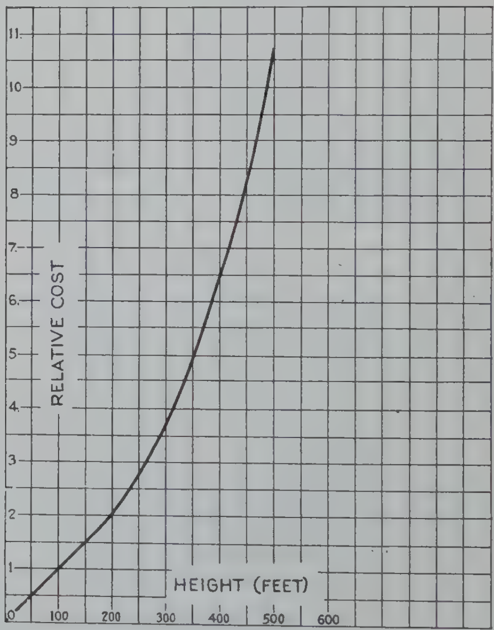


Fig. 46

antenna. For any antenna, it is found that a ground system consisting of 120 buried radial wires, each one-half wave long, is desirable.

The economic factor is of great importance. For a station using a nondirectional antenna, the saving due to the use of a short antenna is large. However, when a directional array is used, the amount of money saved by using an eighth-wave antenna in preference to a quarter-wave assumes rather important magnitudes. Fig. 46 shows relative tower costs as a function of tower height. We see that the curve is linear only for heights less than 200 feet. Fig. 47 gives the heights of eighth- and quarter-wave antennas as a function of frequency. Fig. 48 was constructed from Figs. 46 and 47, and shows the ratio of the cost of a quarter-wave tower to the cost of an eighth-wave. Let us now

compare the cost of two arrays, operating on a frequency of 900 kilocycles. The first array consists of two quarter-wave towers. The second

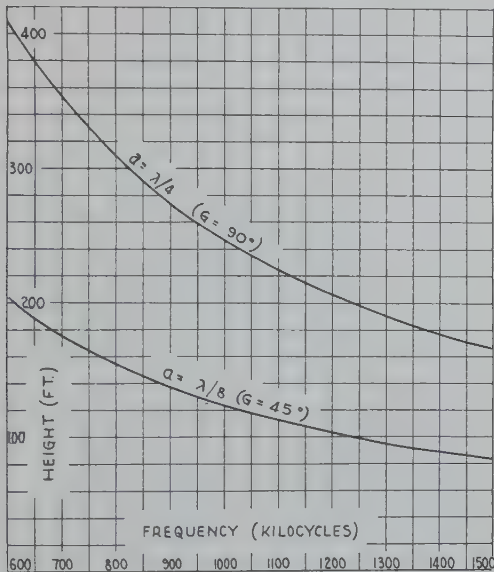


Fig. 47

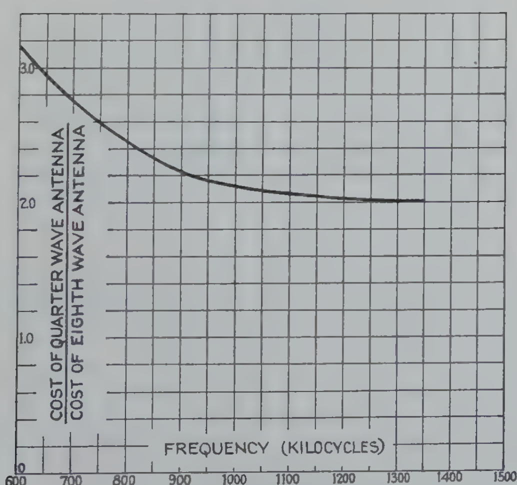


Fig. 48

consists of four eighth-wave towers. From Fig. 48 we see that the first array would cost 11.0 per cent more than the second array. Further, the use of four towers in the second array would allow a more effective

distribution of energy, with more satisfactory coverage. At 600 kilocycles, the first array would cost 1.575 times the second array.

A study of the properties of coupling systems shows that the short antennas may be fed with good efficiency if low-loss inductances are used in the coupling system. Sufficient money will be available due to the use of the short antenna to allow the use of a slightly more efficient coupling system than would ordinarily be required.

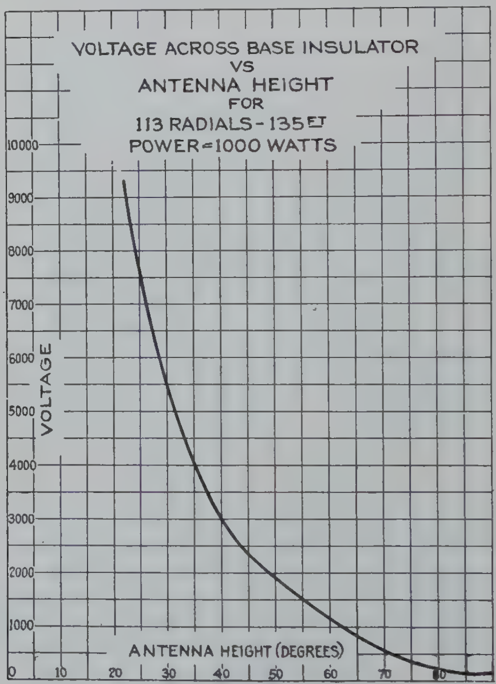


Fig. 49

Another factor of some importance is the base insulator voltage. For a given antenna height, the base voltage is

$$E = \sqrt{\frac{W}{R}}\sqrt{R^2 + X^2} \qquad (13)$$

where,

E = r-m-s volts for an unmodulated carrier
W = carrier power (watts)
R = antenna resistance
X = antenna reactance.

Fig. 49 shows this voltage as a function of antenna height, for a power of 1000 watts and a ground system consisting of 113 radials, each 0.417 wave length long. To obtain the peak volts for a modulation of 100 per cent, these values should be multiplied by 2.828. The base voltage for $G = 45$ degrees is many times that for $G = 90$ degrees. Thus the insulators must be somewhat more efficient. It is significant, however, that the wooden base insulator used in the experiments did not noticeably affect the efficiency.

Too much emphasis cannot be given to the fact that, where direct field intensity along the ground is the sole aim, the ground system is of more importance than the antenna itself. Many times in the past, a T antenna and a poor ground system have been replaced by a tall tower antenna and an extensive ground system with a resulting large increase in field intensity which has been attributed to the tower alone.

CORRESPONDENCE

Election of Institute Officers

I noticed recently that Professor Hazeltine had written a letter to the Institute commenting on the method now used in selecting officers. I was particularly interested in this because it represented the views which I have had for some time.

I feel like Professor Hazeltine that it would probably be desirable from the point of view of the welfare of the Institute for the Nominating Committee to nominate not more than one candidate for each of the higher offices to be filled. Under such a setup it would, of course, be possible to make additional nominations by petition.

I think that such a procedure could very well be applied to all the elective offices including the Board of Directors as well as the President and Vice President. However, if there is a considerable group who think this is going too far, it might be possible to nominate two candidates for each vacancy in the Board of Directors, as is now done, but only one candidate for the remaining offices.

Changes such as Professor Hazeltine and I would like to see made in the nominating system would naturally place increased responsibility on the Nominating Committee and would, I believe, make it desirable to formulate some systematic method of selecting this committee so that it would be representative of the membership as a whole. Some form of geographical representation proportioned according to membership would appear desirable. Thus each section might select one member to the committee, with National Headquarters selecting an additional group to represent the New York territory and other groups that are not included in a regular section. If the Nominating Committee held its meeting at the time of the annual convention, there would be no difficulty in getting representation from all sections, except possibly the three on the Pacific Coast, and even the Pacific Coast sections could probably usually be represented either by one of their own members who happened to be in the east at the moment or some former member of their section whom they could designate to represent them.

It would seem that this general problem of the method of selecting officers is of sufficient importance to warrant being given detailed study to see if it would not be possible to devise a system that would be more representative of the membership as a whole and also which would not create unfavorable reactions among the important membership of the Institute which undoubtedly result from the present system of handling elections. It would seem that if there is some interest in this that the proper procedure would be to appoint a committee to study the methods which other engineering societies use in electing officers and to draft a constitutional amendment to put into effect the results of this study.

F. E. Terman

Stanford University, California

Proceedings of the Institute of Radio Engineers
Volume 25, Number 6, *June, 1937*

BOOKLETS, CATALOGS AND PAMPHLETS RECEIVED

The following commercial publications of radio engineering interest have been received by the Institute. You can obtain a copy of any item without charge by addressing the issuing company and mentioning your affiliation with the Institute of Radio Engineers.

Measuring Instruments—Laboratory Apparatus

Cathode-Ray Oscillographs • • • "Du Mont Oscillographer" is a new monthly bulletin. March and April issues already issued. (4 pages, $6\times9\frac{1}{4}$ inches, printed.) *Allen B. Du Mont Laboratories, Inc., Upper Montclair, N. J.*

Cathode-Ray Oscilloscope • • • A parts list and wiring diagram for an oscilloscope using the 913 tube given in bulletin S D-266. (2 pages, $8\frac{1}{2}\times11$ inches, printed.) *Thordarson Electric Manufacturing Company, 500 W. Huron Street, Chicago Ill.*

Cathode-Ray Oscillograph • • • The model 820 midget oscillograph has "dual amplifiers" and a linear sweep circuit. (2 pages, $8\frac{1}{2}\times11$ inches printed.) *Triumph Manufacturing Company, 4017 West Lake Street, Chicago, Ill.*

Cross-Coil Ohmmeters • • • Three new bulletins describe ohmmeters and resistance-measuring test sets, all of the "Megger" type. Bulletin 1490, recording and indicating instruments for continuous and semi-continuous duty, 12 pages; Bulletin 1495, direct-reading circuit-testing instruments, 4 pages; Bulletin 1500, ground-resistance testers, 8 pages. ($8\frac{3}{4}\times10\frac{1}{2}$ inches, printed.) *James G. Biddle Company, 1211 Arch Street, Philadelphia, Pa.*

Measurements of Distortion, High Speed • • • "Distortion Measurements in the Broadcasting Station" and "High Speed Measurements with the Strobotac" are the subjects of two articles in the April, "Experimenter." (8 pages, 6×9 inches, printed.) *General Radio Company, 30 State Street, Cambridge, Mass.*

Miniature Instruments • • • A new line of miniature panel-type instruments are listed in catalog section 43–350. (16 pages, $8\frac{1}{2}\times11$ inches, printed.) *Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.*

Resistance Bridges and Precision Resistors • • • A new catalog describes the Shallcross line of instruments and resistors. (20 pages, $6\frac{1}{4}\times9$ inches, printed.) *Shallcross Manufacturing Company, Collingdale, Pa.*

Strain Measurement • • • A method of using a piezo-electric strain gauge for high-frequency strain measurements is described in the March, 1937, issue of "Brush Strokes." (12 pages, $4\frac{3}{8}\times5\frac{7}{8}$ inches, printed.) *Brush Development Company, 3322 Perkins Avenue, Cleveland, Ohio.*

Test Equipment • • • Although the new RCA test-equipment catalog is primarily for servicemen some of the instruments it describes have application in the engineering laboratory. (34 pages, $8\frac{1}{2}\times11$ inches, printed.) *RCA Manufacturing Company, Inc., Camden, N. J.*

VACUUM-TUBE VOLTMETER • • • The May, 1937, issue of the "Experimenter" gives a complete description of the new type 726A vacuum-tube voltmeter. (8 pages, 6×9 inches, printed.) *General Radio Company, 30 State Street, Cambridge, Mass.*

BROADCAST TRANSMISSION EQUIPMENT

COAXIAL LINE • • • Complete coaxial transmission line systems (both air- and gas-filled) are described in Bulletin No. 101. (4 pages, $8\frac{1}{2} \times 11$ inches, printed.) *Isolantite, Inc., 23 Broadway, New York, N. Y.*

MICROPHONES • • • Specifications and characteristics of the Western Electric 633A Dynamic Microphone are given in this bulletin. (12 pages, 8×11 inches, lithographed.) *Graybar Electric Company, 420 Lexington Avenue, New York, N. Y.*

PROGRAM AMPLIFIER • • • The new Western Electric 110A Program Amplifier has an automatic volume limiter. (8 pages, 8×11 inches, lithographed.) *Graybar Electric Company, 420 Lexington Avenue, New York, N. Y.*

PICKUPS • • • Description and specifications of Model 99A Crystal Record Reproducer are given in Data Sheet No. 205. (2 pages, $8\frac{1}{2} \times 11$ inches, lithographed.) *Shure Brothers, 225 West Huron Street, Chicago, Ill.*

SPEECH INPUT ASSEMBLY • • • A new 8-page bulletin gives specifications on the new Collins 12H Speech Input Assembly. (8 pages, $8\frac{1}{2} \times 11$ inches, printed.) *Collins Radio Company, Cedar Rapids, Iowa.*

RADIO COMMUNICATION EQUIPMENT

AIRCRAFT RECEIVERS • • • Two aircraft radio receivers (Models AVR-10 and 10-A) are described in a new bulletin (5120). (4 pages, $8\frac{1}{2} \times 11$ inches, printed.) *RCA Manufacturing Company, Inc., Camden, N. J.*

RECEIVER • • • A new "Super-Pro" receiver is described in bulletin 1005. (6 pages, $8\frac{1}{2} \times 11$ inches, printed.) *The Hammarlund Manufacturing Company, Inc., 424 West 33rd Street, New York, N. Y.*

MANUFACTURING AIDS

AIR CONDITIONING • • • Odor absorbers for ventilating systems are discussed in an 8-page bulletin. ($8\frac{1}{2} \times 11$ inches, lithographed.) *Consolidated Air Conditioning Corporation, 114 East 32nd Street, New York, N. Y.*

VACUUM TESTING • • • Bulletin 403 describes two short-wave oscillators for glow and vacuum testing in vacuum-tube manufacture. (1 page, $8\frac{1}{2} \times 11$ inches, lithographed.) *Lepel High Frequency Laboratories, Inc., 39 West 60th Street, New York. N. Y.*

MATERIALS—METALS, INSULATION, DIELECTRICS

MICA, CLOTH, PAPER • • • Catalog No. 11 summarizes William Brand & Company's line of insulating materials. (16 pages+cover, $5 \times 8\frac{1}{4}$ inches, printed.) *William Brand & Company, 276 Fourth Avenue, New York, N. Y.*

NICKEL ALLOYS • • • A new technical information bulletin (No. T-12) gives suggestions for machining Monel, nickel and nickel alloys. (16 pages, $8\frac{5}{8} \times 11$ inches, printed.) *The International Nickel Company, Inc., 67 Wall Street, New York, N. Y.*

PAPERS, FABRICS • • • Catalog Section 65–040 lists Westinghouse insulating materials. (4 pages, $8\frac{1}{2} \times 11$ inches, printed.) *Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.*

COMPONENTS

INVERSE FEEDBACK • • • The April, 1937, issue of "The Aerovox Research Worker" summarizes the principles and applications of stabilized feedback amplifiers. (4 pages, $8\frac{1}{2} \times 11$ inches, printed.) *Aerovox Corporation, 70 Washington Street, Brooklyn, N. Y.*

RELAYS • • • Bulletins 81, 131, and 362 describe, respectively, intermediate-duty, heavy-duty, and motor-driven time-delay relays. (8, 4, and 2 pages, $8 \times 10\frac{1}{2}$ inches, printed.) *Ward Leonard Electric Company, Mount Vernon, N. Y.*

RESISTORS • • • This new catalog lists fixed and adjustable wire-wound resistors of the enamelled, precision, and flexible types. (12 pages+cover, $9 \times 11\frac{1}{8}$ inches, printed.) *Electrad, Inc., 175 Varick Street, New York, N. Y.*

RADIO-FREQUENCY TRANSFORMERS • • • Bulletins 2537 and 2538 list air-core and iron-core transformers, radio-frequency chokes, and power-line filters. (6 pages, $8\frac{1}{2} \times 11$ inches, printed.) *J. W. Miller Company, 5917 So. Main Street, Los Angeles, Calif.*

VIBRATORS • • • New 1937 catalog describes vibrators and converters for original equipment and replacement service. (20 pages, $8\frac{3}{8} \times 11$ inches, lithographed.) *Electronic Laboratories, Inc., Indianapolis, Ind.*

TUBES

APPLICATION NOTES—(RCA) • • • The following application notes have been received: Index, 4 pages; No. 69, 250-volt, low-current operation of the 6L6, 9 pages; No. 71, high-power operation of two 6L6's in push-pull, 5 pages; No. 72, two 6L6's operated at 40 watts class AB_2, 10 pages; No. 73, operation of the 25L6 in typical circuits. ($8\frac{1}{2} \times 11$ inches, printed and lithographed.) *RCA Manufacturing Company, Harrison, N. J.*

THYRATRONS—(WESTINGHOUSE) • • • Technical data on 10 thyratrons is given in Information Bulletin No. 9. (4 pages, $8\frac{1}{2} \times 11$ inches, lithographed.) *Westinghouse Electric and Manufacturing Company, Bloomfield, N. J.*

TUBE DATA—(NATIONAL UNION) • • • An index of National Union engineering tube data has just been issued together with releases on "Cathode Loaded Amplifiers" and the 6E5 Tuning Indicators. (12 pages, $8\frac{1}{2} \times 11$ inches, lithographed.) *National Union Laboratories, 1181 McCarter Highway, Newark, N. J.*

TUBE DATA—(RAYTHEON) • • • The 10th edition of the Raytheon tube-data chart has just been issued. (1 page, $20\frac{1}{4} \times 18\frac{3}{4}$ inches, lithographed.) *Raytheon Production Corporation, 420 Lexington Avenue, New York, N. Y.*

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